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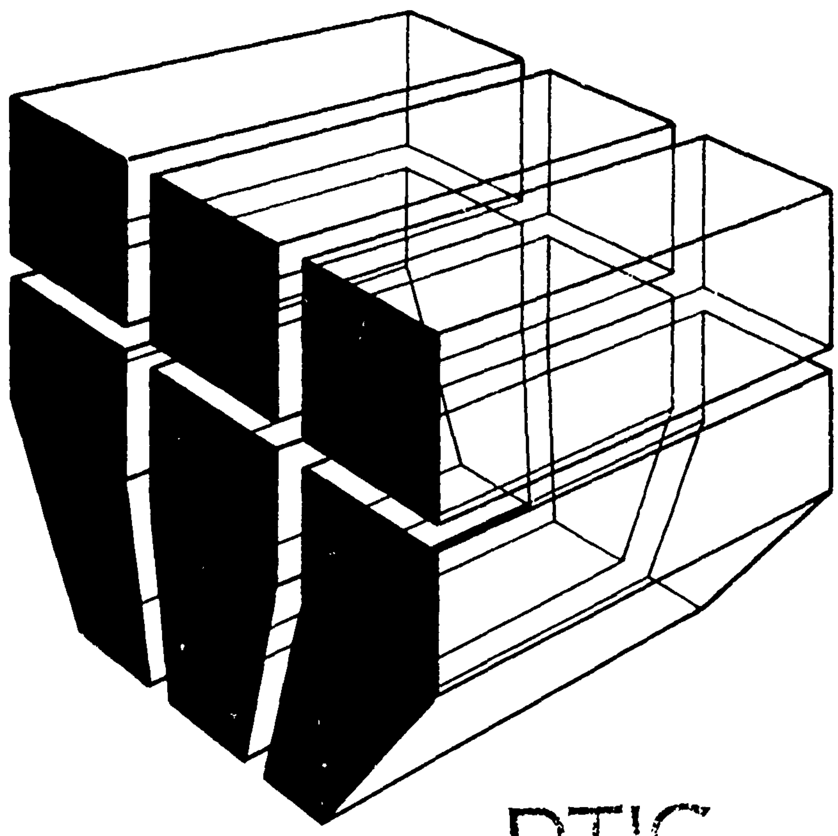
December 1983

MUNITIONS STORAGE CONCEPTS FOR USE IN FLAT TERRAIN: VOLUME I, FACILITY DESIGN



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The objective of this project was to develop feasible concepts for weapon storage facilities located in flat terrain with a high water table. The result of the study is preliminary design of six feasible storage complexes. Both aboveground and underground structures are proposed. The special construction practices necessitated by the high water table are addressed. Each design is capable of containing the hazardous effects of an internal explosion within the bay of occurrence. The facilities are also designed to survive

such external threats as detonation of 300,000 pounds of high explosive 100 meters away from the structure, a direct hit by a 500 pound bomb, a B747 air craft impact on the roof, and a sophisticated terrorist attack. Furthermore, under chemical warfare conditions, the facilities can continue the weapon loadout process while maintaining a clean environment within the structure. Twenty-five year life cycle cost estimates are included for each of the six designs. After examination of the costs, loadout times, daily operational efficiencies, and equipment needs of the six concepts, concepts 1, 3, and 4 were chosen as the most viable for consideration.

Volume I contains a narrative description of the evolutionary design process that led to the six proposed designs, a technical discussion of the design constraints imposed by the various threat scenarios, and a detailed description of the six facility designs. Volume II documents the engineering calculations supporting the structural designs and the life cycle cost calculations. Plan and section drawings are provided for each of the six facilities.

FOREWORD

This research was conducted for the Defense Nuclear Agency (DNA) by the Engineering and Materials Division (EM) of the U.S. Army Construction Engineering Research Laboratory (CERL) under DNA RDT&E funds for FY 1982, Task Code A99QAXFC. The study was prepared for CERL by the Southwest Research Institute, San Antonio, TX, under DACA88-82-C-0013. Dr. Anthony Kao was the CERL Contract Project Officer. MAJ L. T. Messenger was the DNA Technical Monitor.

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Dr. R. Quattrone is Chief of CERL-EM. COL Paul J. Theuer is Commander and Director of CERL and Dr. L. R. Shaffer is Technical Director.

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd)

TABLE OF CONTENTS (Cont'd)

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Cont'd)

LIST OF ILLUSTRATIONS (Cont'd)

LIST OF TABLES

1.0 INTRODUCTION

1.1 Background

Many weapon storage facilities that are being used by the Department of Defense (DOD) are fairly old and were designed and constructed to meet a set of requirements that was developed some years ago. These requirements were based primarily on explosive safety, with little or no consideration given to other factors, such as security or operational efficiency. Thus, there is a need to develop a family of storage facilities that will meet updated DOD requirements and can be used in different topographical, geological, and climatic locations.

Developing these new facilities involved generating new weapons storage concepts encompassing several specific design and functional requirements and criteria:

1. The concepts should be applicable in level terrain; in particular, the geographic and climatic conditions should be limited to those found between Houston and Galveston, Texas. Particular emphasis should be placed on the problems associated with a high water table and deeply buried bedrock.

2. A maximum loadout time for any facility layout concept was specified. A group of 5-1/2- and 2-1/2-ton trucks with two personnel per truck would carry off one group of items as a unit. The largest facility would have a total of four groups of items.

3. Any handling equipment would already be approved by the Nuclear Regulatory Commission.

4. Explosive quantity, package size, and numbers of weapons to be stored were provided.

5. The containment design and storage compartment size would be planned for the largest item, since the facility will be used interchangeably for various types of weapons.

6. A "design fragment" was to be determined for considering a primary fragment hazard.

7. Total containment should be provided in storage bays and the maintenance area for the accidental explosion of one item. The storage bays will have a predetermined group of items; however, sympathetic detonation among items in the same group must be prevented so that only one item would be lost in an accident. Blast valves will be needed on the air-handling systems. The facility must have accident assessment capability, with remote monitoring.

8. The exterior security/survivability threats to be considered include:

    a. Attack by a commando squad with shoulder-fired weapons; hand carried explosive; high-velocity, slug-forming, plate or cone weapons; automatic weapons, hand tools

    b. 500-lb GP bomb

    c. 300,000 lb of high explosives (HE), surface burst at 100 meters

    d. Boeing 747 aircraft impact into roof

    e. Chemical weapons environment outside.

The structure should prevent enemy personnel from entering for 30 minutes. After any one of these threats is over, the facility should be able to conduct business as usual. The chemical threat should only be considered for out-loading, not for incoming shipments.

9. Work flow will be either from storage to dock to outside or from storage to maintenance to storage.

10. The maintenance bay will require a 4000-lb overhead crane.

11. The facility design should consider reusability for a purpose other than munitions storage in case the use of the facility is redirected.

12. No accident potential need be assumed during transport.

13. Backup generators and mechanical systems require the same degree of hardness as the reset of the facility.

14. During cost estimation, the preciseness to which the concepts have been estimated should be indicated. The labor rates are to be comparable to those for San Antonio.

15. An EMR clean environment and an OSHA-approved warehouse environment are to be provided.

16. In comparing different storage concepts, the relative importance of rating factors will be: manpower requirements, survivability/ security, safety, loadout time, cost; less important factors will be real estate and signature minimization (i.e., the facility is not to be recognized by local citizens as a weapons storage facility).

17. Constraints placed on concepts by current explosives safety standards can be violated if they cause significant compromise to survivability and security requirements.

1.2 Purpose

The purpose of this investigation was to develop a minimum of six feasible concepts for storing particular types of weapons in accordance with Government requirements and specifications and to recommend three of these storage systems for final development.

2.0 PROJECT APPROACH

Information regarding external threats, internal hazards, operational requirements, and geographic conditions was evaluated and used to determine the best facility layouts. Facility "layouts" are distinguished here from "concepts." A *layout* considers space efficiency, internal accident containment, equipment needs inside the facility, chemical protection, and operational efficiency inside the facility. A *concept* considers a layout in conjunction with load dock operations, location of layout above or below ground, superstructure design for external threats, and effects of subsurface conditions. The process for layout selections is indicated in part A of Figure 2-1. Weapons bay layouts were determined based on safety, space efficiency, and equipment types. Preliminary sizes of support, control, maintenance, and load dock areas were provided by the Government at the first project meeting. These areas were combined with the weapons bay types to produce numerous facility layouts. The layouts were separated into groups, with each group including permutations of the same basic plan. To concentrate on the layouts which provided the best operations, a rating scheme was devised to evaluate individual layout groups separately; the groups included similar members, thereby selectively reducing the number of acceptable layouts. The six layouts which best combined the requirements were then chosen.

The concept synthesis process included the six layouts as input toward total concept design. Part B of Figure 2-1 illustrates this process. As shown, the layouts were separated into aboveground or underground concepts with a superstructure design to resist exterior threats. The load-out operations were determined with entrances and load docks modified to match. Some preliminary design, evaluation, and then redesign was necessary in the areas of mechanical equipment and foundations.

After the final concept designs were determined, design drawings were made, including floor plans and wall sections, and costs for each were estimated. A scheme was then established to evaluate the six concepts in terms of meeting operational and security needs (part C of Figure 2-1). The

six concepts were then evaluated accordingly, and the results used to select the three best concepts.

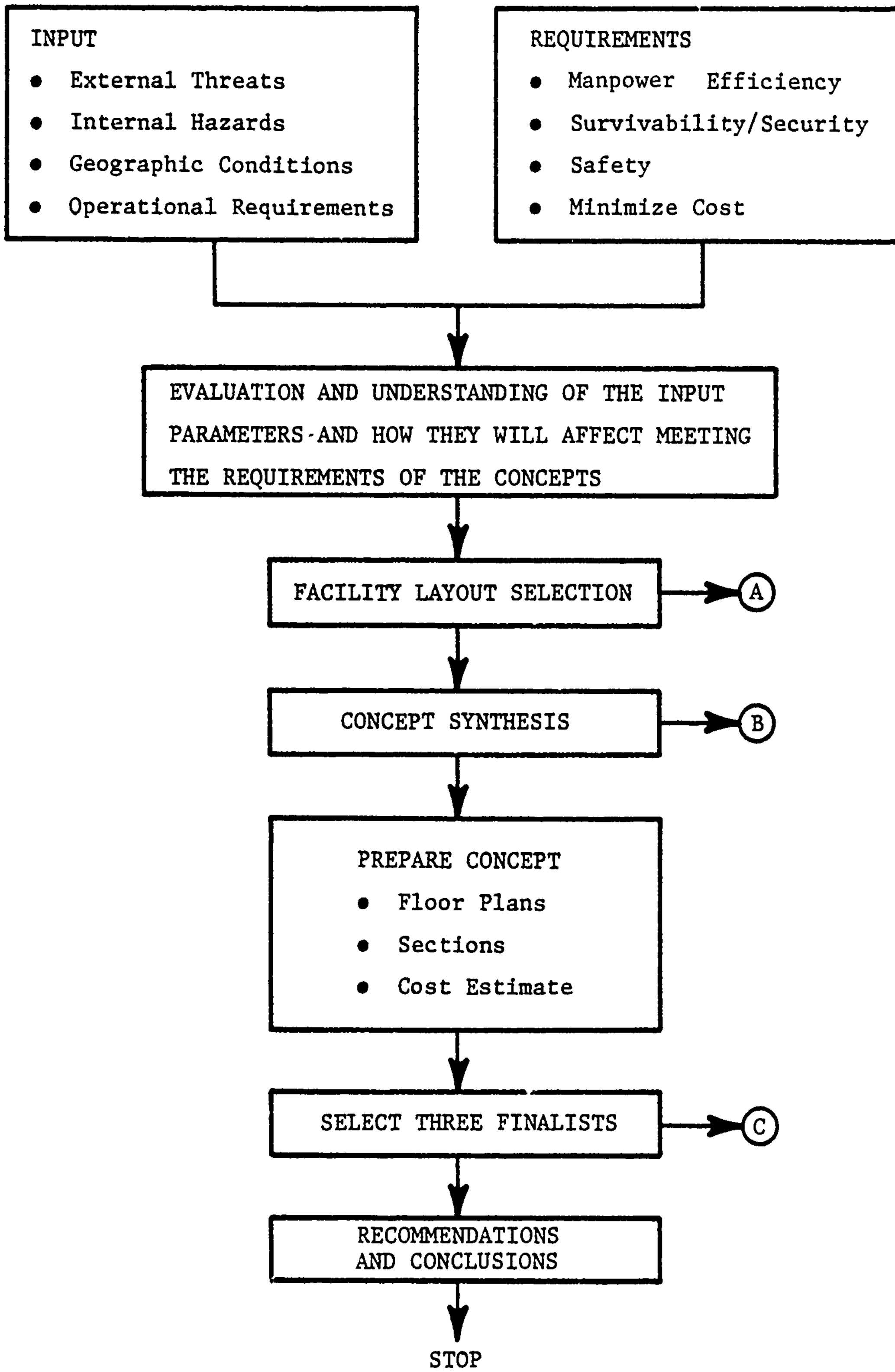


Figure 2-1. Concept Development

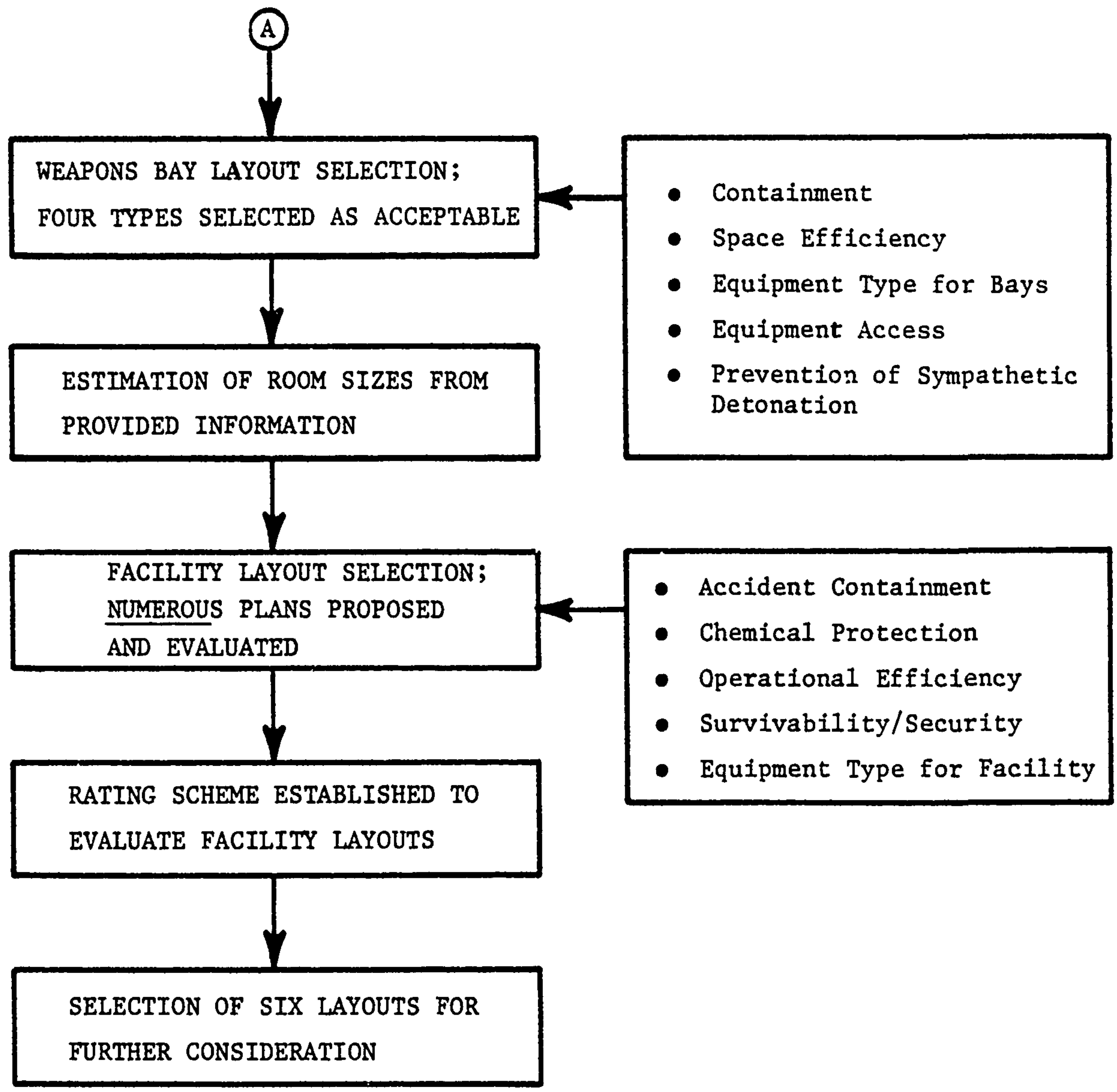


Figure 2-1A. Facility Layout Selection

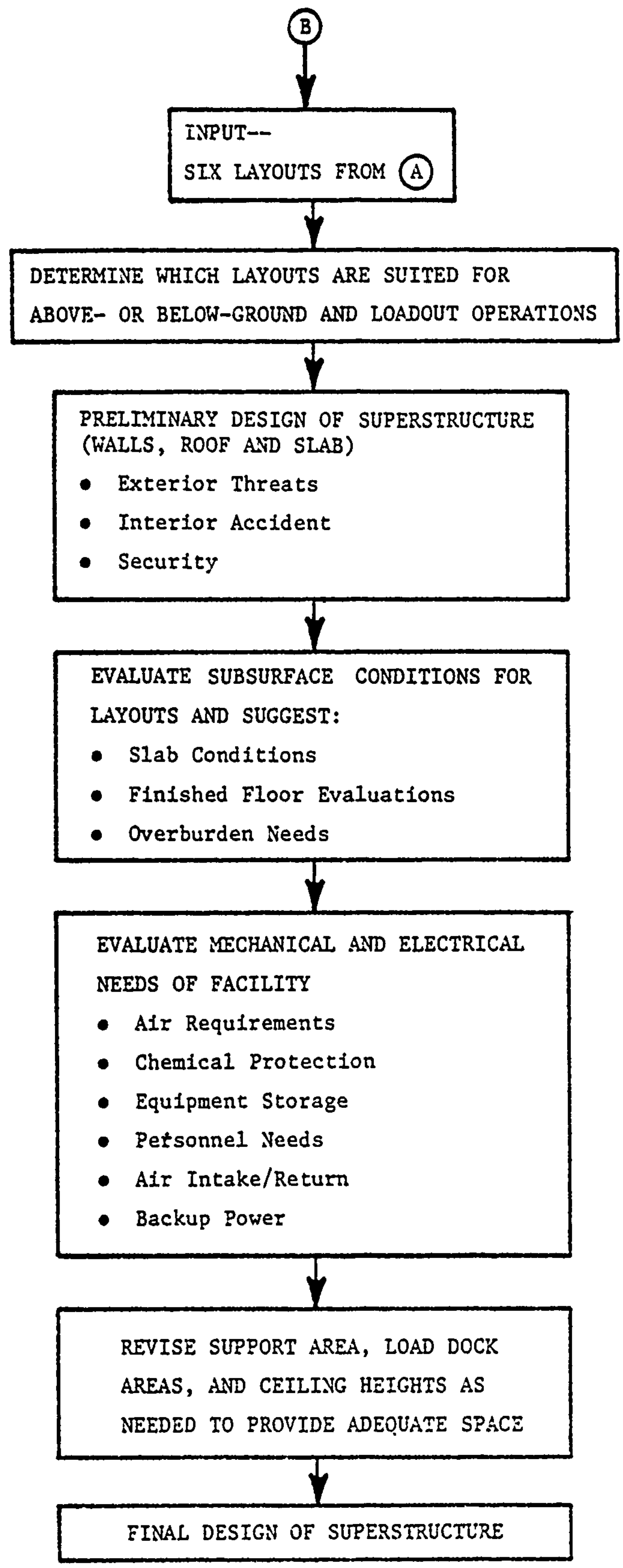


Figure 2-1B. Concept Synthesis

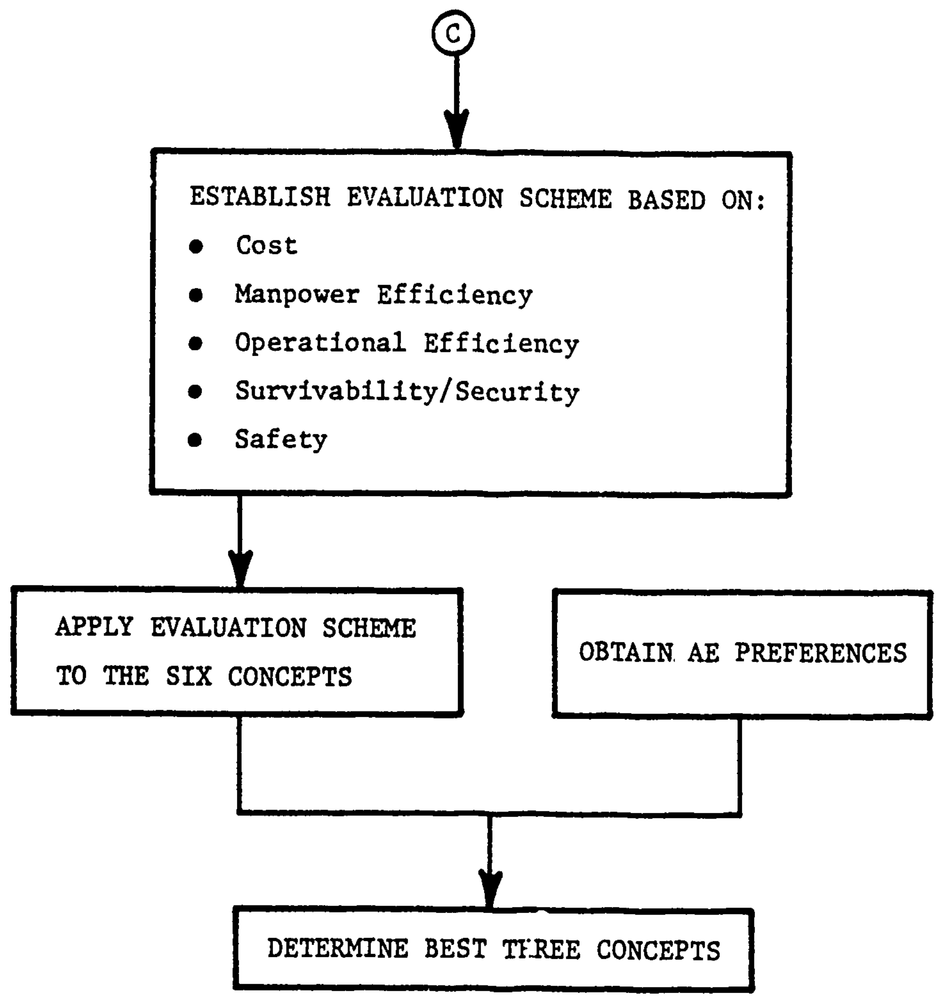


Figure 2-1C. Selection of Three Finalists

3.0 OPERATIONAL AND SECURITY REQUIREMENTS FOR MUNITIONS STORAGE

Howdyshell (Ref. 3-1) gives an excellent review of work at the Construction Engineering Research Laboratory related to munitions storage concepts. Results and findings to the date of his paper (Sept. 1980) are discussed in four major categories -- safety, security, shelter, and operations. In our background discussions, we draw freely on this paper, and on many other references in the literature of ammunition and explosives safety.

3.1 Safety

The foundations for military safety regulations are found in a series of DoD Regulations and Standards (Ref. 3-2 to 3-6). In particular, AMCR 385-100, AMC Safety Manual (Ref. 3-2) contains safety policy considerations for such things as nuclear and conventional weapon handling and maintenance, quantity-distance storage criteria, and classification and storage guidelines. The importance of this document, and the archaism of the current design philosophy, is found in Paragraph 18-1, a portion of which is quoted below:

"New storage magazines should be of the earth-covered, corrugated steel or reinforced concrete arch-type."

It is, however, apparent that this requirement is not always followed, and that box-shaped, earth-covered magazines are in common use (Ref, 3-1), have been tested in model scale (Ref. 3-7), and can be designed to meet safety criteria (Ref. 3-7).

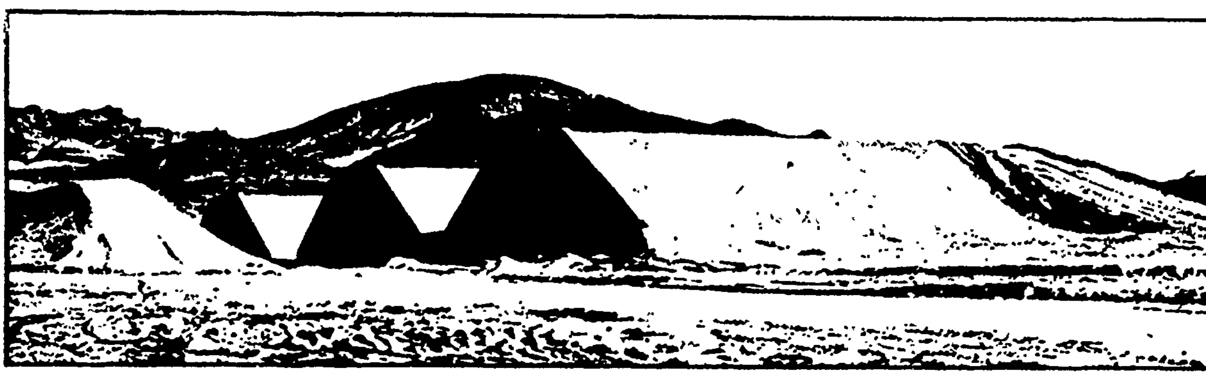


Figure 3-1. "Standard Igloo"
(Ref. 3-21)

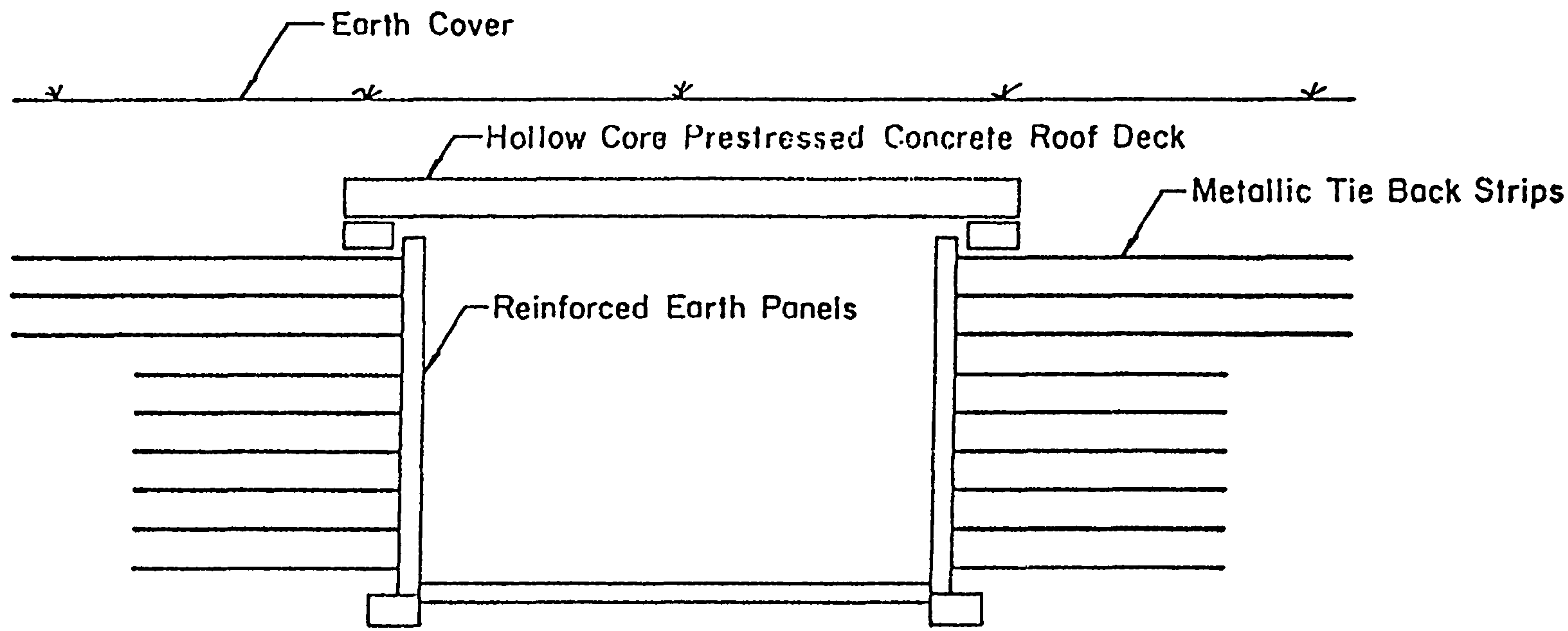
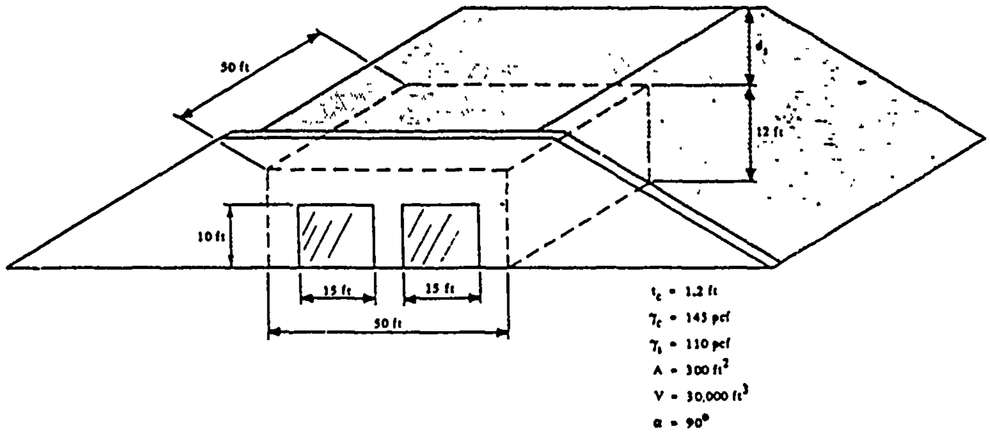
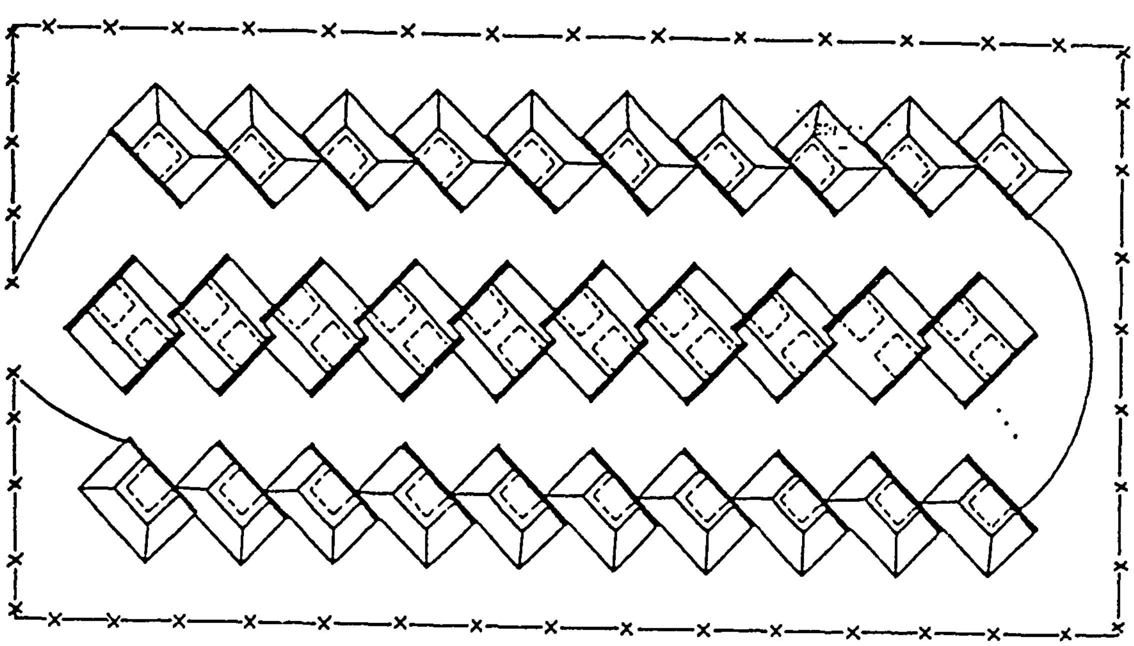


Figure 3-2. Reinforced Earth Ammo Storage Concept
(Ref. 3-1)



a. Box Storage Magazine



b. Herringbone-Pattern Layout

Figure 3-3. Navy Rectangular Magazine Concept
(Ref. 3-7)

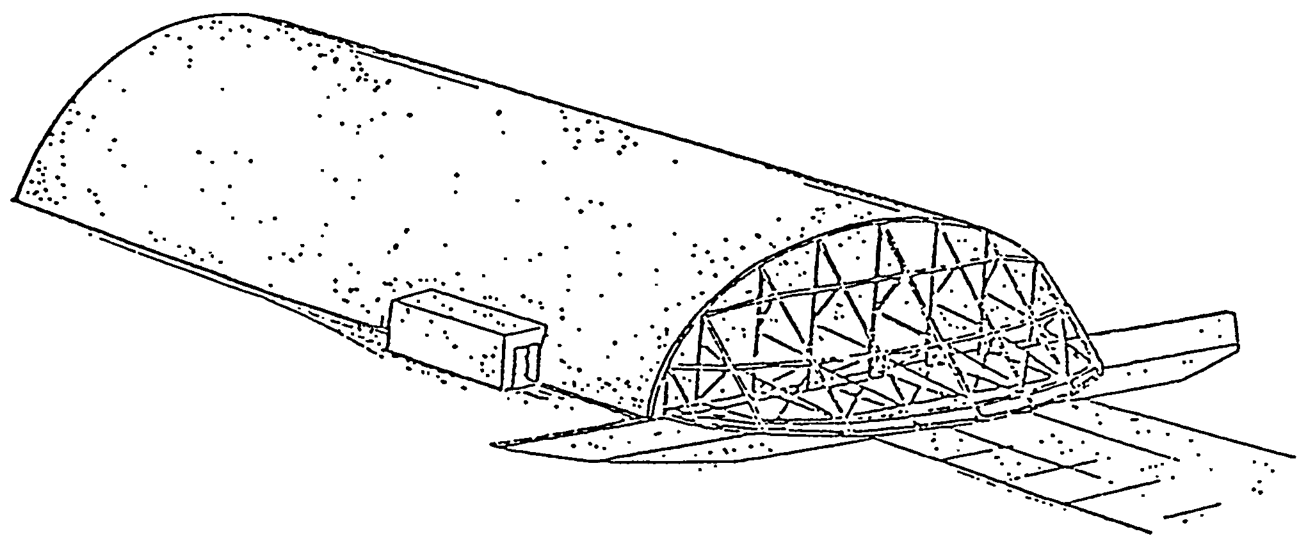


Figure 3-4. U. S. Air Force Third-Generation Aircraft Shelter

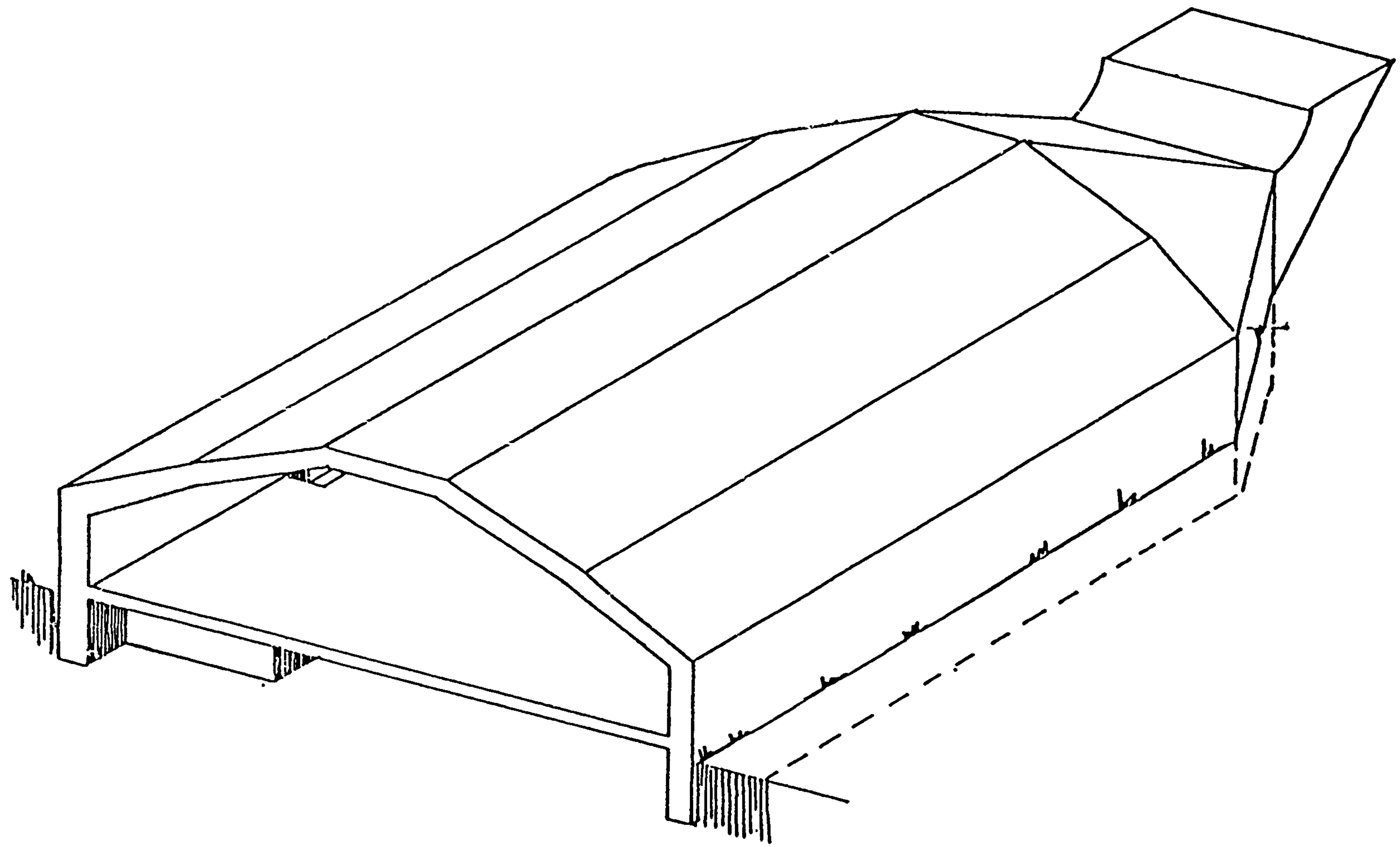


Figure 3-5. Norwegian Aircraft Shelter

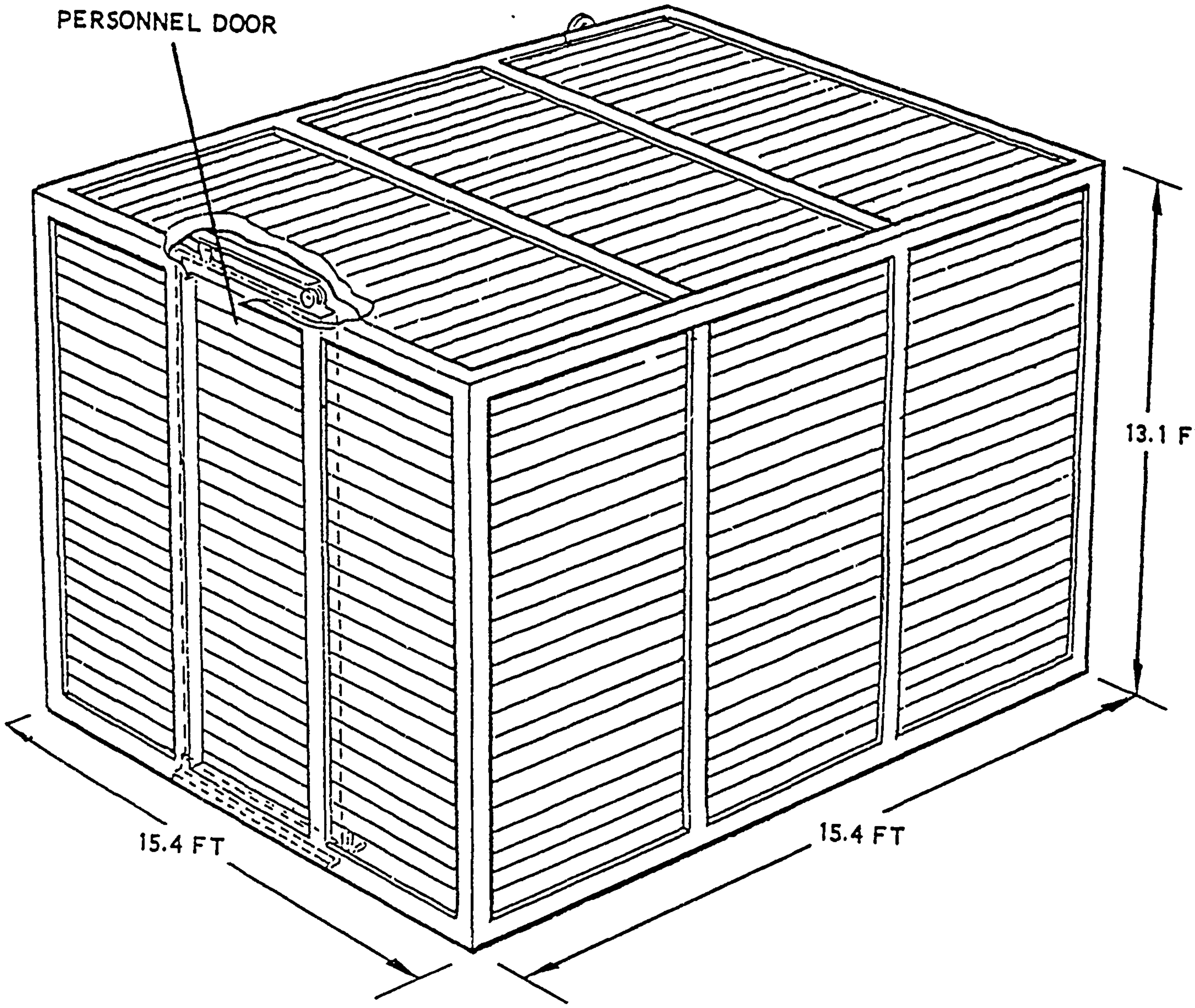
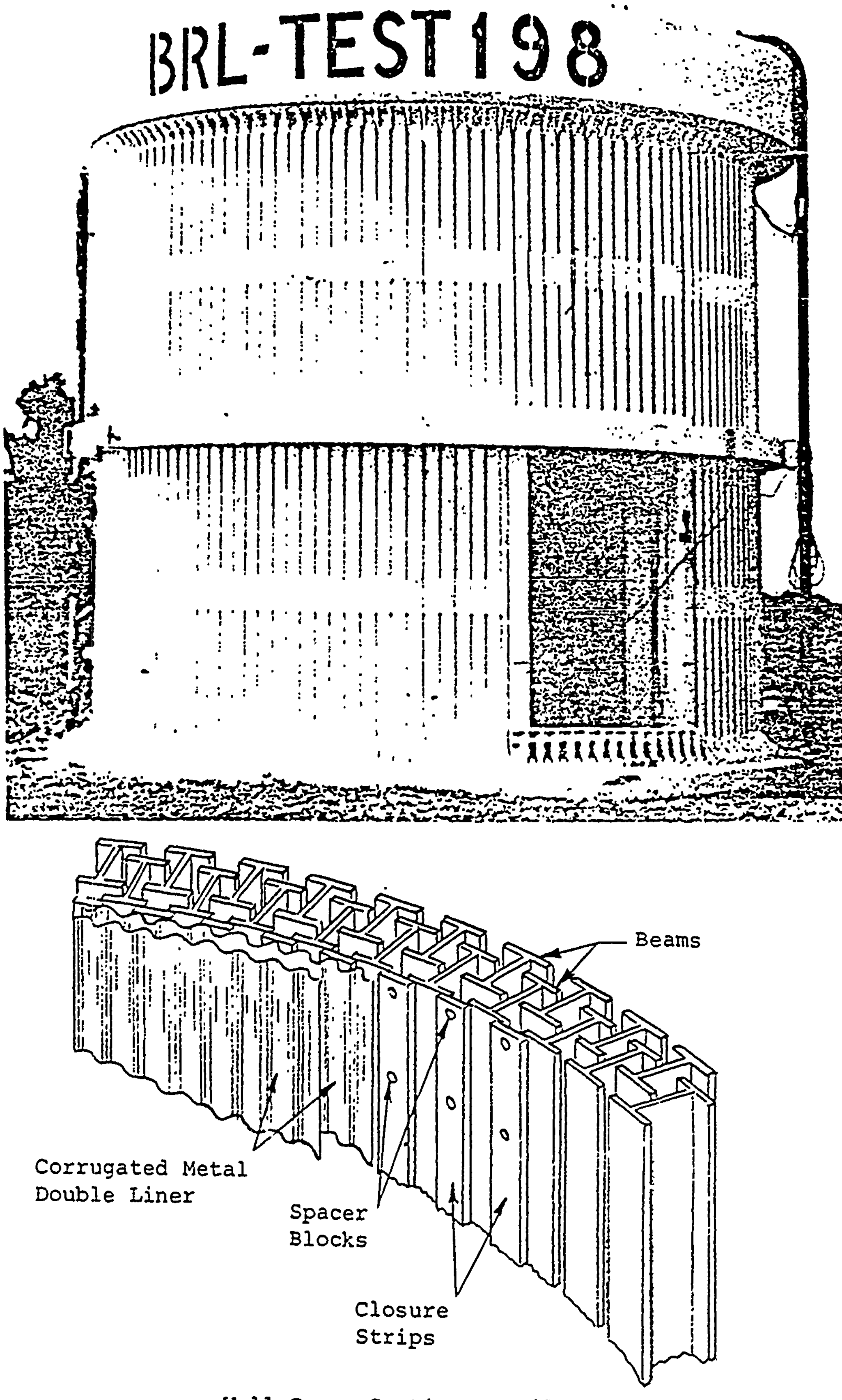


Figure 3-6. Typical Box-Shaped Suppressive Shield



Wall Cross Section Detail

Figure 3-7. Typical Cylindrical-Shaped Suppressive Shield

The development of the quantity-distance relationships in use in the U.S. can be followed in the reports of Petes, et al., (Ref. 3-8) and Roylance (Ref. 3-9). These relationships specify the minimum distances between adjacent storage magazines, between the magazine and inhabited buildings, and between the magazines and other public use features.

The Department of Energy (DOE) has supplemented the requirements of AMCR 385-100 with its own requirements for operations involving high explosives (Ref. 3-10). These requirements are designed to address the particular problems associated with the DOE nuclear munitions (HE-plutonium) facilities. In addition to AMCR 385-100, the DOE manual relies heavily on TM 5-1300 (Ref. 3-11) for design criteria.

The requirements contained in References 3-2 and 3-11 have manifested themselves in many ways. They specify the distances between individual magazines, distances to inhabited buildings, and distances to public highways, and thus dictate the amount of real estate which must be devoted to storing a given amount of explosives. Wall thicknesses and the strengths of various structural members are specified, as are, in many cases, the types and locations of materials required to provide these strengths. The ultimate influence is found in the quotation above which specifies exactly what type of magazine is to be built in the future. Nothing in any of these regulations, however, even suggests that the user should have an efficient, even usable, facility.

3.2 Security

These requirements can probably best be summarized by a quote from Ref. 3-1:

> *"Ammunition storage facilities should provide for the prevention of loss of material and/or information to enemies, subversives, vandals, or indigenous animals. Security requirements should include the following.*
>
> *(1) Stored material should be protected against damage from direct hits with small arms, and near misses with large arms.*

(2) Stored material should be completely protected against damage from indigenous animals.

(3) The site should inhibit access to the stored material by intruders.

(4) There should be consistency in design to support the security requirement (no weak links); e.g., security systems will be integrated into the design.

(5) Storage facilities should have multiple access.

In addition, security requirements should comply with Ref. 3-12.

Security protection should be provided with the minimum initial and operating costs and with the minimum manpower requirements possible."

A considerable amount of effort has been devoted in recent years to the design and evaluation of physical security concepts. Moore (Ref. 3-13) has evaluated the effects of the first threat-level tools on a variety of barrier panels. Garza (Ref. 3-14) has tested various hand tools, power tools, exo-lance burn rods, and linear shaped charges against a variety of brick, reinforced concrete, and steel targets. The objective of these programs is the determination of the length of time required by personnel using the various tools to defeat the target protective structure, assuming that the attack is not interrupted by security personnel. The number of guards and their response time requirements are, thus, functions of the protection provided by the storage facility against a given threat and of the warning devices in use.

As can be seen from the definition in the introduction of the security threat for the proposed facility, the threat is very severe, and facility design features to defeat this threat must be carefully considered.

3.3 Survivability

One of the primary requirements of any military storage facility should be the protection of the contents from direct military action by an enemy.

This action may be intended to destroy the stored material, to deny its usage by preventing access to it, or contaminating it through chemical, biological, or radiation attack. Any of these objectives can be accomplished through the use of conventional, nuclear, or chemical weapons.

Conventional weapons (bombs, rockets, artillery and mortar shells containing high explosives) have several attack mechanisms associated with their use against storage facilities. The overpressure produced by their detonation can damage or destroy a structure and leave the contents exposed to further attack or to the environment. These pressures, and the impulses associated with them, can be estimated from compilations of extensive field data (Ref. 3-15, for example). The structural response of the facility to these loads can then be determined using even relatively simple analysis methods (Ref. 3-16). The shell or bomb can actually penetrate the wall or roof of the structure and destroy the building contents through its own detonation, and the sympathetic detonation of other nearby explosives, or through detonation of the stored explosives through impact.

Collapse of the storage structure may not cause destruction of the contents but may prevent their use by denying access to them through the debris and earth cover of the structure. Conventional weapons may also be used to attack highways, railroads, or landing strips, further denying access to the stored material. The period of time for which access is denied is limited to that required to remove the debris or repair the damage, and there are no long-range effects, such as radiation or chemical contamination, from conventional weapons.

Nuclear weapons can damage or destroy a structure and/or its contents through overpressures, radiation, ground motion, and cratering effects. The overpressure-time history of a nuclear blast can be calculated using the experimental data fits of Brode (Ref. 3-17) or the calculations of the Air Force (Ref. 3-18). The methods of Ref. 3-16 (repeated in handbooks such as Refs. 3-11, 3-19, or 3-20), can again be used to determine structural response.

3.4 Operations

Some general operational requirements for the storage facilities are listed in Ref. 3-1, and we quote:

> *"The operational requirements for ammunition storage facilities are the ability to move the material in and out of storage and the ability to perform required operation and maintenance on the material while in storage. Other specific operational requirements are as follows.*
>
> *(1) The structure should be able to accommodate all types of explosives and ammunition.*
>
> *(2) The structure should be designed to maximize storage efficiency. This should include (a) no interior beams or columns to interfere with storage operations and (b) ceiling heights over the entire floor area sufficient for a 16-foot stacking height.*
>
> *(3) Doors should be large enough to accommodate the largest item stored and the equipment required to transport the item. They should be located to minimize loss of storage space to forklift operating areas and should be protected from foul weather interfering with their use.*
>
> *(4) The interior of the structure should be of a light color, and lighting should be available and recessed. Ventilation should be sufficient to remove noxious fumes.*
>
> *(5) Access roads should be all-weather and able to withstand the heaviest axle loads.*
>
> *(6) Each structure should be provided with a hard surface area which will permit material-handling equipment to operate in and out of the structure and to and from the transport equipment with no obstructions/impediments."*

These general requirements are supplemented or restricted for this study by the more specific requirements listed in the Introduction.

3.5 Geographical, Climatic and Topographic Limitations

In general, such limitations can impose a wide variety of constraints on construction techniques. In this contract, we are limited to considering only level terrain, with high water table and poor foundation conditions.

3.6 Other Considerations

In addition to the factors noted in 3.1 through 3.5, other functional needs may well influence the design of munitions storage facilities. Some such needs, which are partially affected by climatic conditions, are listed in Reference 3-1, and are quoted here:

"Shelter requirements for ammunition storage are that long-term (20 years or more) and short-term preservation of the stored material is provided so that the material is usable when needed. Shelter requirements should include the following.

(1) The shelter should protect the material (and its packaging) from moisture-induced degradation.

(2) The shelter should protect the stored material from extreme temperatures and large time-temperature gradients.

(3) The shelter should protect its contents from natural catastrophies such as external fire, lightning, and high winds."

Storage of chemical munitions can introduce special requirements because of the extreme toxicity of the agents in these munitions. These requirements can include the need for continuous monitoring for agent leakage, elaborate alarm systems in the event of leakage, and careful planning for personnel evacuation, and for decontamination in the event of serious leaks.

As can be seen in the Introduction, we must indeed consider a chemical weapons attack in this concept study. Also, another important consideration is resistance to crash impact of a Boeing 747 aircraft. The effect of both of these requirements on the concepts is considered in detail in this study.

3.7 Related Work in Explosion-Resistant Facility Design, Construction and Evaluation

The current large-capacity storage unit, the "standard igloo," is shown in Figure 3-1 (from Ref. 3-21). The earth cover over the steel arches, together with the separation between individual bays, prevents propagation of an explosion from one bay to another. The entrances are so oriented that the blown-off doors do not present a hazard to other structures. The doors on one end provide equipment access, and the elevated position of the earth cover favors good drainage and a lower moisture content.

A proposed storage concept (from Ref. 3-1) is presented in Figure 3-2. The patented Reinforced Earth®* technique is used to provide lateral reinforcement to the prefabricated vertical walls. The below-ground position of Figure 3-2 would prevent blast propagation from one bay to another, and the system could also be built in an aboveground and mounded configuration. The below-ground configuration would provide a relatively constant temperature for the stored contents, but the difficulty of this type of construction in hard rock is obvious.

A rectangular storage chamber has been proposed by the Navy (Ref. 3-7). A single chamber and a proposed herringbone pattern are shown in Figure 3-3. The doors of the individual chambers are arranged to preclude blast damage from one to another, and the arrangement provides good equipment access to each bay. Again, earth cover is used to prevent blast propagation. Physical security of the compound would be aided by the relative closeness of the doors and good viewing angles by passing security personnel.

Another storage concept, similar to the igloo, could evolve from the U.S. Air Force third-generation aircraft shelter. A sketch of this shelter is shown in Figure 3-4 (from Ref. 3-22). This type of structure has a design hardness level of 15 psi (side-on overpressure) for a long-duration blast, and the clam-shell doors provide easy access to the stored contents. Modification of the aircraft shelter (i.e., removal of the exhaust plume escape ports and weapons vault) could produce a very good magazine design. The

*Registered trademark of the Reinforced Earth Co., Arlington, VA.

Norwegians also have evolved a hardened aircraft shelter design (Figure 3-5) which could also be modified to provide a storage facility. This shelter has been tested extensively to determine the effects of interior explosions (Ref. 3-23), and it is also hardened, to an unknown level, against exterior blast attack.

A possible medium-capacity storage concept would include the use of reinforced concrete, earth-mounded structures to contain or attenuate the effects of explosions. This type of design, utilized in Department of Energy weapons production plants, is based on data and requirements of documents such as Refs. 3-10 and 3-11 and is used for explosive weights of up to several hundred pounds. The designs have been tested explosively (e.g., Refs. 3-24 and 3-25) and have proven satisfactory from a safety viewpoint. They have also been built to specifications which include rather stringent security requirements.

There have been a number of types of protective structures which have been analyzed, designed, and proof-tested, either in model-scale or full-scale, for the partial or complete containment of the effects of accidental explosions in explosives manufacturing operations. Many of these designs evolved during the Suppressive Shields Program conducted by Edgewood Arsenal. At least six designs for suppressive shields have been safety approved (Ref. 3-26), and a design handbook has been prepared (Ref. 3-27). Analysis methods are summarized in Ref. 3-28.

These shields are of all-steel construction, using frames and panels made from standard structural steel components, or are of composite construction with reinforced concrete roof and foundation and structural steel walls. They are designed to vent, but strongly attenuate, blast waves and are also designed to arrest high-energy fragments completely. Figure 3-6 shows a typical box-shaped suppressive shield, while Figure 3-7 shows a cylindrical shield. The vented panels for these structures can be made of a number of assemblies using I-beams, angles, zees, louvres, and perforated plates, arranged to vent but to intercept all fragments. A number of cross-sections of shields which have been made and tested appear in Figure 3-8.

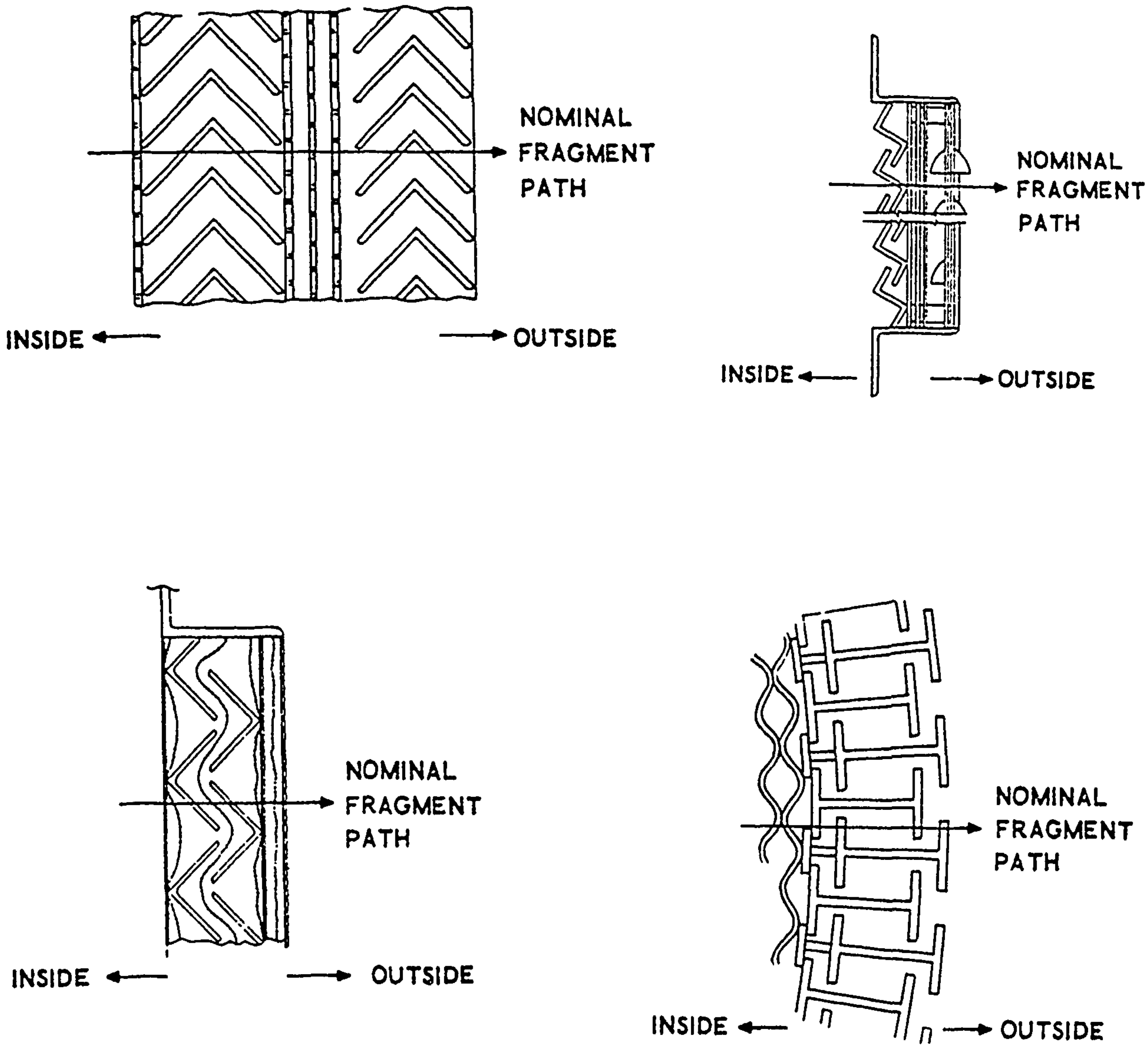


Figure 3-8. Typical Panel Cross-Sections for Suppressive Shields

Some other proven designs for protective structures for explosives operations involve steel double-walled structures with sand fillers between the double walls. Cowan and Willis (Ref. 3-29) report on such a design with I-beam framework and steel roof decking panels as inner and outer walls, and sand between the wall panels. The design is shown schematically in Figure 3-9, while partially complete and completed structures are shown in Figures 3-10 and 3-11. Cylindrical, double-walled structures of similar construction have been designed, built, tested, and patented in Norway (Ref. 3-30). Schematically, this design plan appears in Figure 3-12.

Again, we suggest these double-walled designs as concepts for munitions storage structures for medium storage capacity. The box-shaped structures could prove quite adaptable to multi-box design.

The impact of aircraft on structures has been studied fairly extensively in the nuclear reactor industry. Much of this work has been discussed at conferences on structural mechanics for reactor technology such as described in Ref. 3-31 which represents a compilation of several such important papers. Analysis in this area has included the impact of several aircraft types on reactor vessels. Actual aircraft mass at impact differs from author to author as does the velocity at impact. The various authors have determined design load curves for the various aircraft impacts. All of these curves are derived from calculations of the specific crushable aircraft impacting a rigid barrier. Differences in the curves for the same aircraft occur because of variations in impact mass and/or velocity inputs.

The nuclear industry has also considered the response of underground or earth-covered components subjected to aircraft impact from directly above. Response models incorporating the energy absorption properties of the soil and the underground structure have been considered. Figure 3-13 from Ref. 3-31 depicts a response model for a buried reinforced concrete structure

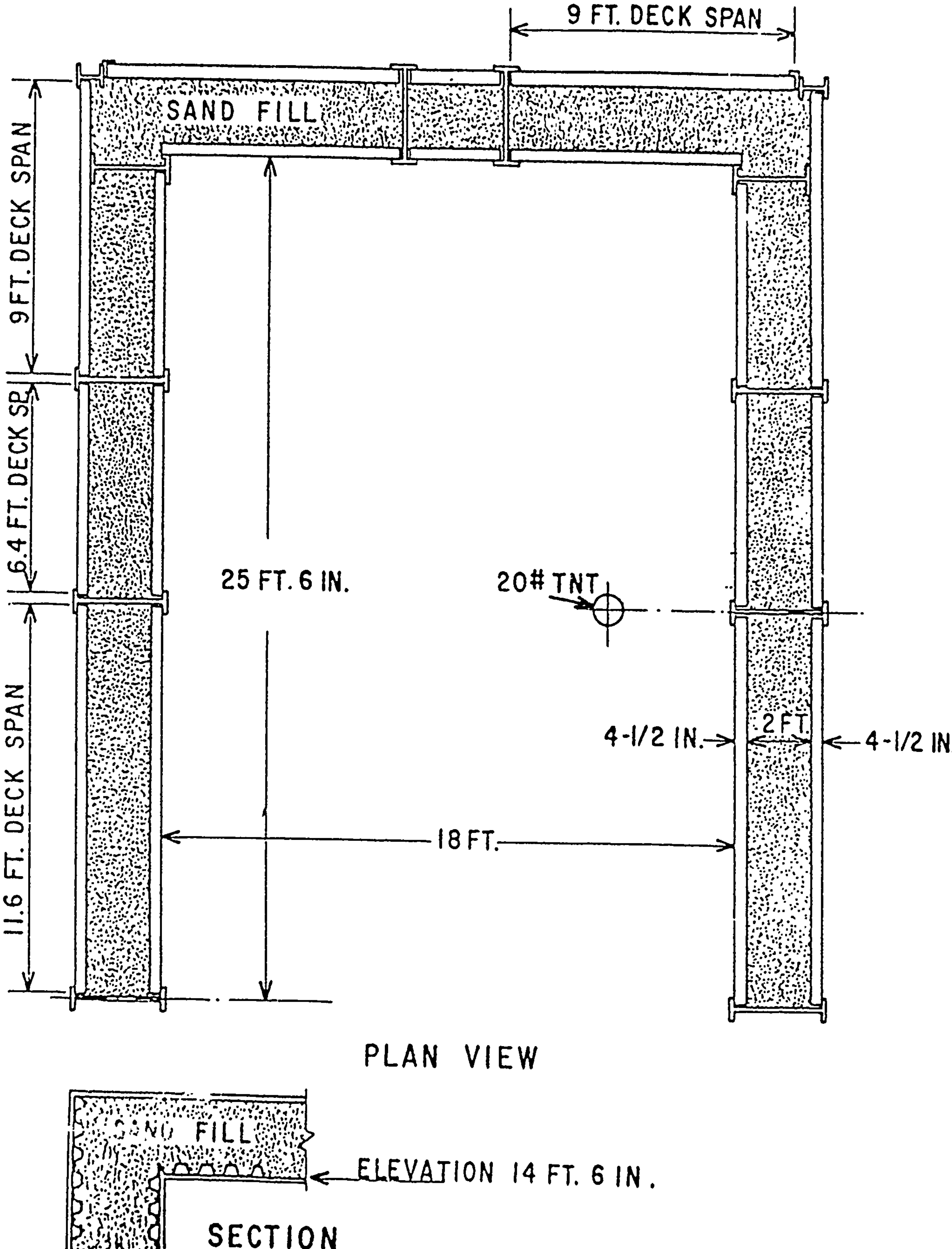


Figure 3-9. Cross-Section of Box-Shaped Double-Walled Barricade

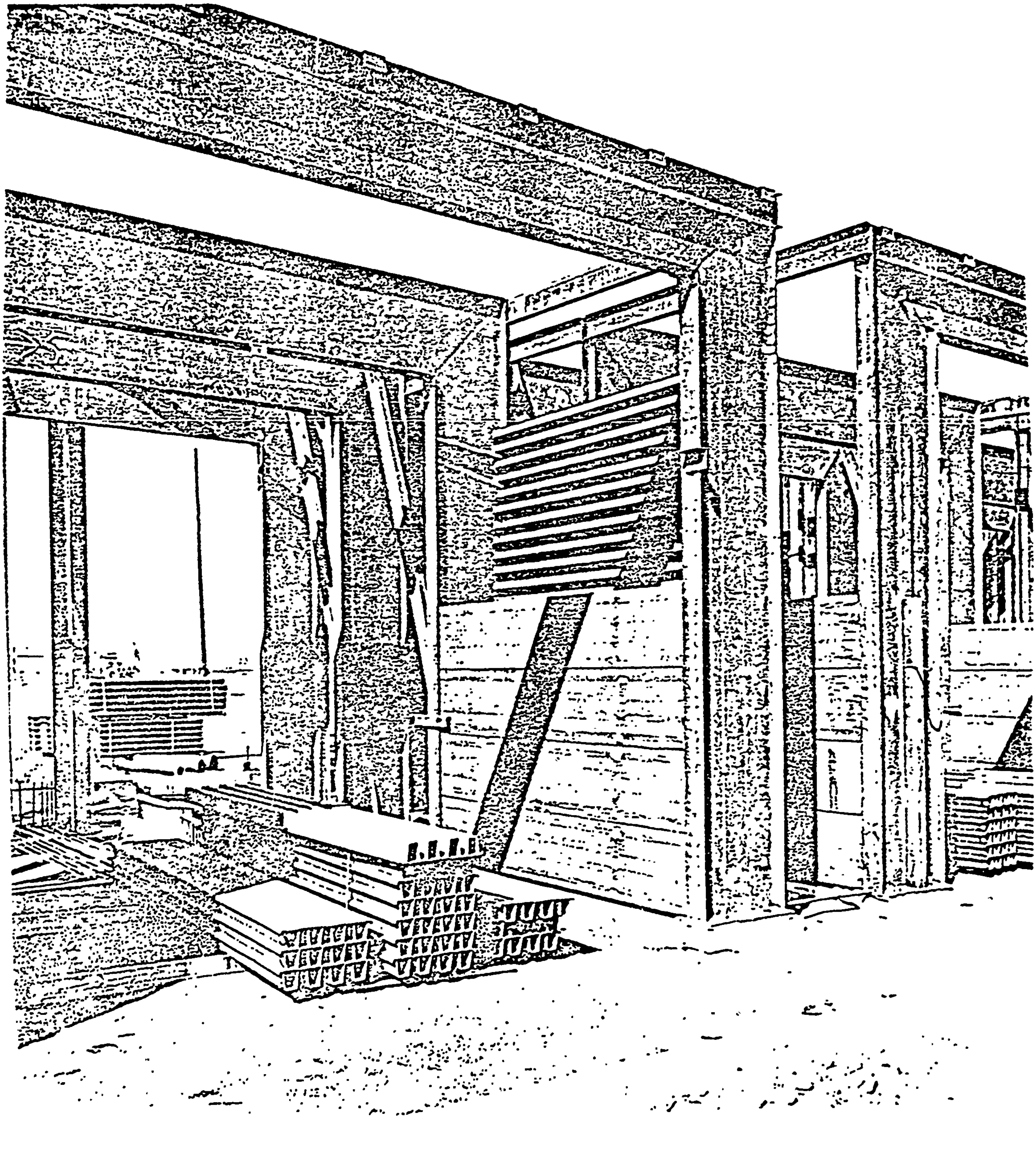


Figure 3-10. Typical Sandwich-Type Construction Showing Corrugated Steel Roof Decking and I-Beam Construction (United States Army Photograph)

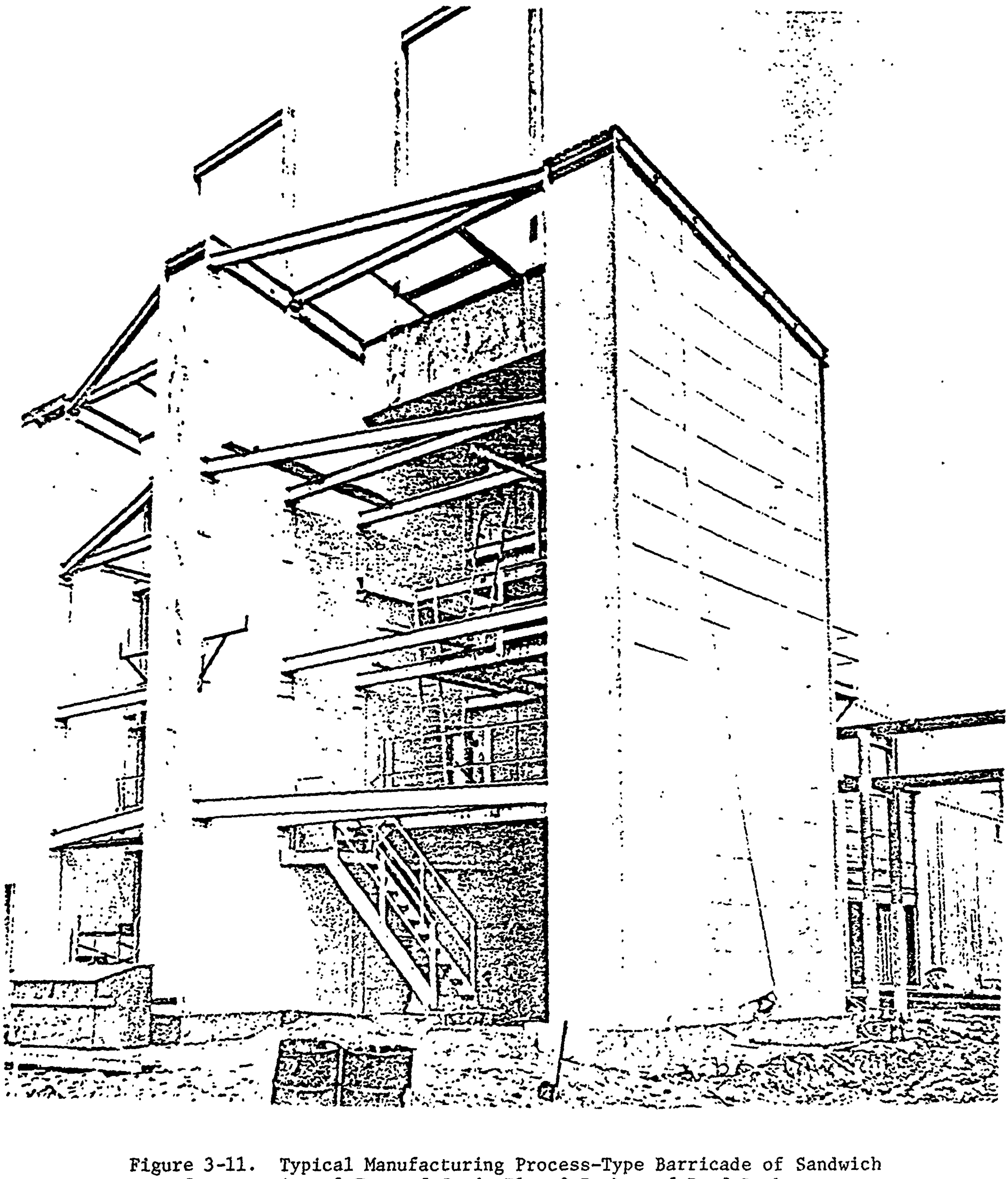
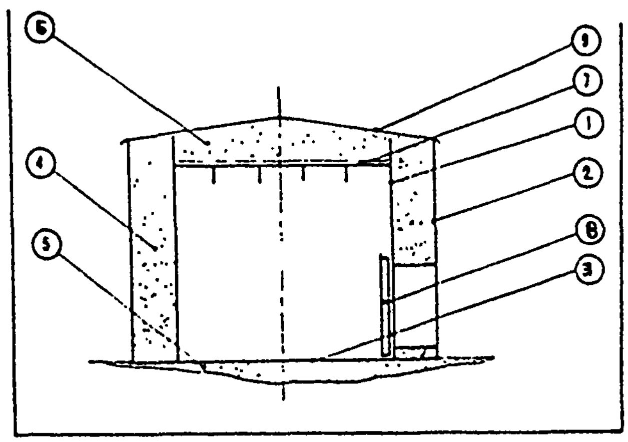


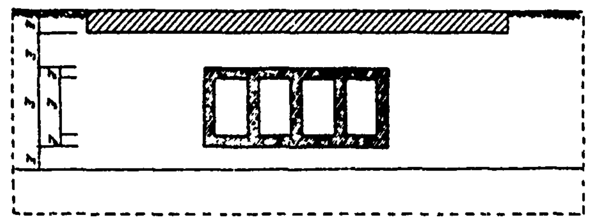
Figure 3-11. Typical Manufacturing Process-Type Barricade of Sandwich Construction, 3 Feet of Sand, Plus 9 Inches of Roof Deck Approximately 30 Feet High



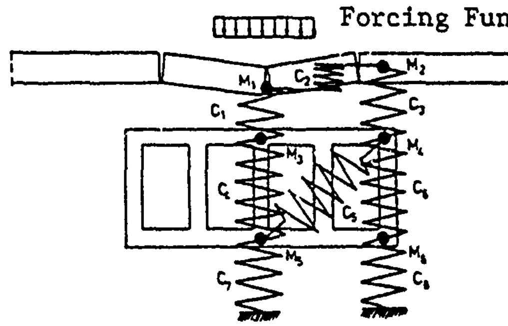
Cross-section of the building.

1. Inner steel cylinder
2. Outer steel cylinder
3. Base plate
4., 5., 6. – Sand
7. Cover of balsawood
8. Steel door
9. Thin plastic cover

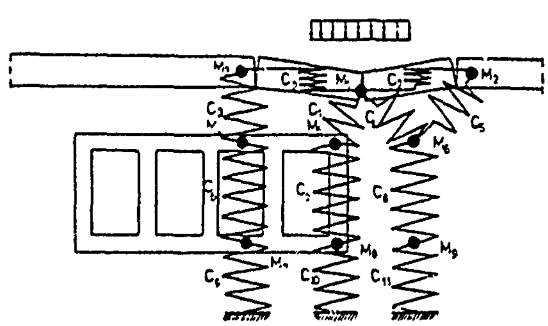
Figure 3-12. Schematic of Dyno Industries Design for Double-Walled Steel Containment Structure



a) undeformed target



b) centered (symmetric) response



c) off center response

Figure 3-13 Aircraft Impact Above a Buried Structure (Ref. 3-31)

with a slab at the upper surface. The forcing function representing aircraft impact is applied to the slab. This scenario is analogous to a below-ground munition facility subjected to an aircraft impact or any forcing function applied to the surface (such as a blast load history).

4.0 TECHNICAL DISCUSSION

The concept study for development of new types of munition storage facilities was guided by numerous constraints and requirements as described earlier. Included in this section is a technical discussion of how these constraints affected the concept development. Technical aspects are discussed in general terms in this section. Application of the factors described in this section to the specific concepts is discussed in Section 5.0.

4.1 Survivability and Security

A major concern in developing munition storage concepts was to protect the stored contents against attack from enemies, subversives, or vandals. The broad spectrum of possible attackers required definition and analysis of a number of threats including:

- Large Aircraft Crash
- General Purpose Bomb Explosion
- Large High Explosive Charge Explosion
- Chemical Attack
- Terrorist Attack.

Damage to the facilities by the above-listed threats can occur through a variety of mechanisms. The objective of the survivability and security assessment was to identify anticipated critical loadings for the munition storage concepts. Once critical loads were determined, roof and wall thicknesses of the superstructure could be designed. Loads were derived for both aboveground and buried construction.

4.1.1 Large Aircraft Crash

The 747 aircraft was specified by the sponsor as the threat for the large aircraft crash. Information was available to describe force-time histories for crashes of several aircraft into rigid walls. Nuclear power plant

analysts and designers reported aircraft crash information at the Structural Mechanics in Reactor Technology Conference (Ref. 4-1). Force-time histories, as shown in Figure 4-1, were given for the following aircraft:

- B707
- F-4
- MRCA
- F-111.

Two separate approaches were taken to determine force-time histories for the 747 based upon available information: Replica Modeling and Specific Momentum Extrapolation. Replica modeling allowed total construction of the force-time history while specific momentum extrapolation provided a check for peak force and load duration.

Replica Modeling - The 707 aircraft is very similar in configuration to the 747. Both have rather long cylindrical fuselages, swept low wings and horizontal stabilizers with the same sweep angles, swept vertical stabilizer, and four engines mounted on pylons below the wings. To predict the 747 force-time history in a crash, it is assumed to be essentially a replica of the 707, to a larger scale, and similitude relations are used to scale an appropriate curve in Figure 4-1.

Some general characteristics of the two aircraft appear in Table 4-1, from Ref. 4-1. Also shown in Table 4-1 are appropriate geometric scale factors (λ) derived using procedures described in Ref. 4-9. If λ is the geometric scale factor obtained by scaling any comparable lengths from the two aircraft, then scaling laws state that all times scale by the same scale factor λ as do lengths, velocities are unchanged, weights or masses scale as λ^3, and forces scale as λ^2.

To scale the force-time history of a 707 to a 747, it seems appropriate to scale the time by λ_L, because the duration of the crash force should be proportional to fuselage length. But, to scale the force amplitudes, a scale factor λ_F related to mass seems more appropriate. So, λ_t (time) is set

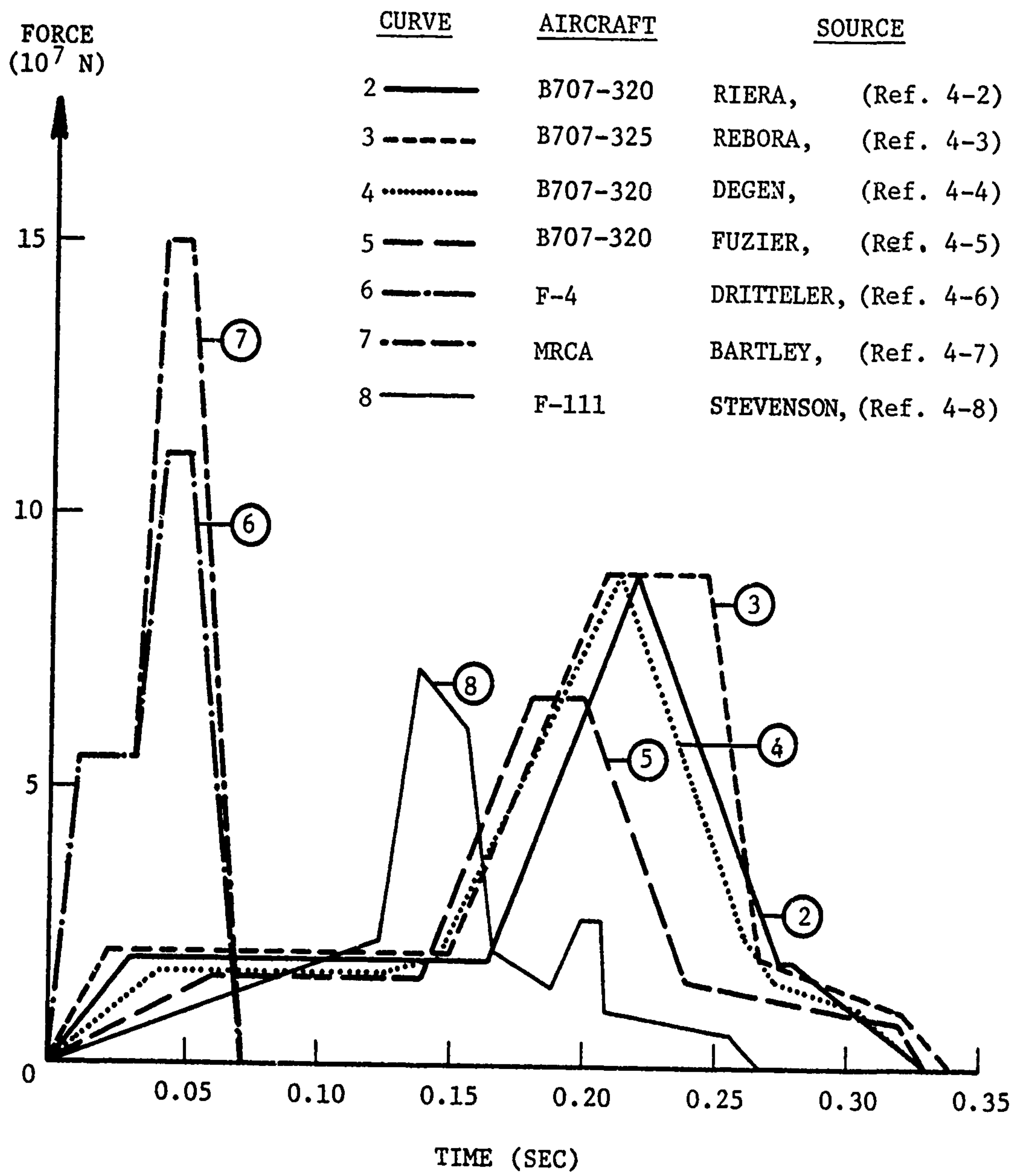


Figure 4-1. Force-Time Curves for Aircraft Crashes (Ref. 4-1)

Table 4-1. Replica Model 707

	707	747	λ	Symbol
Wing Span (m)	44.4	59.6	1.34	λ_S
Fuselage Length (m)	44.4	68.4	1.54	λ_L
Fuselage Diameter (m)	4.0	6.8	1.70	λ_D
Takeoff Weight (kg)	150,000	372,000	1.35*	λ_{TO}
Landing Weight (kg)	112,000	286,000	1.37*	λ_{LG}

* $\lambda^{1/3}$

as $\lambda_t = \lambda_L = 1.54$, and an average is taken between the two values based on mass scaling for $\lambda_F = \left(\frac{\lambda_{TO} + \lambda_{LG}}{2}\right)^2 = 1.85$.

Using the derived scale factors and the force-time history for the 707 aircraft, a force-time history for a 747 crash was constructed and is shown in Figure 4-2. This curve can be used as a conservative (upper limit) forcing function for a 747 crash, because it is based on a head-on crash into a rigid wall.

Specific Momentum Extrapolation - While replica modeling was used to produce a complete force-time history for a 747 crash, an alternate method was used to check peak forces and load duration. Impact data for several aircraft are given in Ref. 4-1 and listed in Table 4-2. Aircraft dimensions are given in Ref. 4-10 and listed in Table 4-3. Peak force during the aircraft crash should vary according to the specific impact momentum (momentum per unit area). Using the impact data and aircraft characteristics given, specific momentum versus peak force is shown in Figure 4-3. For 747 aircraft impacting at speeds between 100 and 120 m/sec, peak forces of 12 to 17 x 10^7N can be expected, depending upon aircraft weight. Duration of the load will vary with the length and stiffness of the aircraft fuselage. Figure 4-4 plots fuselage length versus load duration for the aircraft data given. The upper curve is expected to be more representative of the 747 aircraft because the 707, similar in stiffness to the 747, is the major influence on the curve development. Using the upper curve, the load duration for the 747 aircraft is approximately 0.49 seconds. Thus, load-time histories for 747 aircraft crashing into rigid walls should have peak forces and load durations near the following:

- Peak Force 12 to 17 x 10^7N
- Load Duration $\approx$ 0.49 sec.

These values compare closely to the 18.3 x 10^7N peak load and 0.52 second duration determined using replica modeling. Force-time histories constructed with modeling procedures were used for designing the superstructure.

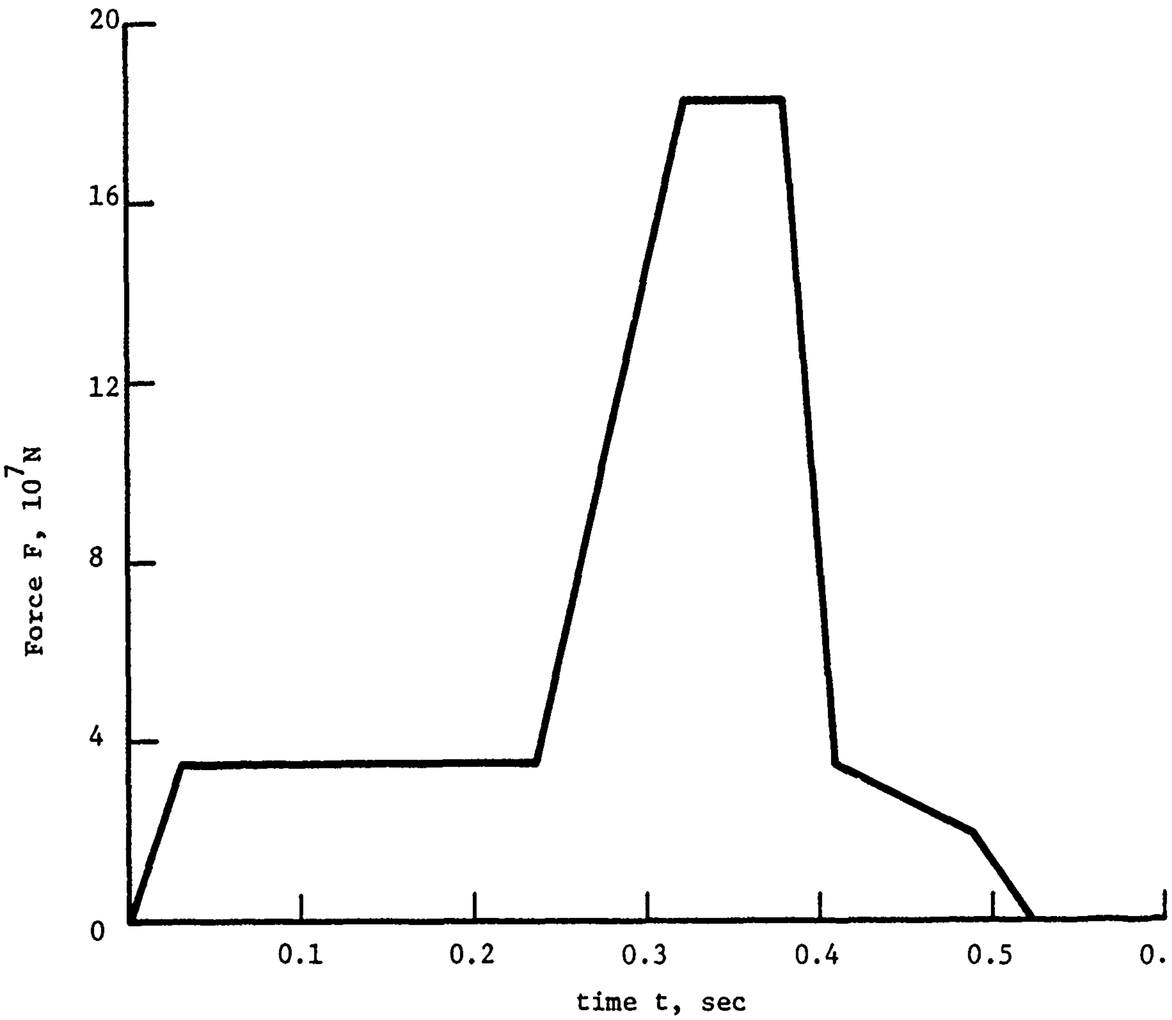


Figure 4-2. Force-Time History for Crash of a 747 Aircraft

Table 4-2. Impact Data

(From Ref. 4.1)

Aircraft Type	Aircraft Mass 1,000 kg	Impact Speed (m/s)	Impact Area m^2	Peak Load 10^7N	Load Duration (sec)	Momentum M·v 10^6 Ns	Impulse $\int F(t)dt$ 10^6 Ns
B720	72.4	103	18-36	7.1	----	7.46	7.37
B707-320	97.6	103	18-36	8.9	0.35	10.1	9.24
B707-320	--	103	28	8.8	0.36	--	11.4
B707-320	90.0	103	10-40	8.8	0.35	9.27	9.12
B707-320	100.0	83	28	6.8	0.35	8.83	7.26
F4	20.0	215	7	10.8	0.07	4.30	4.31
MRCA	25.0	215	7	15.1	0.07	5.38	5.35
F111	41.5	89	--	7.3	0.27	3.69	4.91

Table 4-3. Aircraft Dimensions

Aircraft Type	Wing Span (m)	Length (m)	Diameter (m)	Max. Take-Off Weight (kg)
B-720	39.0	39.2	4.0	106,100
B707-320	44.4	44.4	3.8	151,300
B747-200B	59.6	68.4	6.8	351,000
B747-200C	59.6	68.4	6.8	372,000
F4	11.7	17.8	2.0	20,865
MRCA	8.6-13.9	14.1	1.8	18,145
F111	10.3-21.9	20.8	1.9	41,500

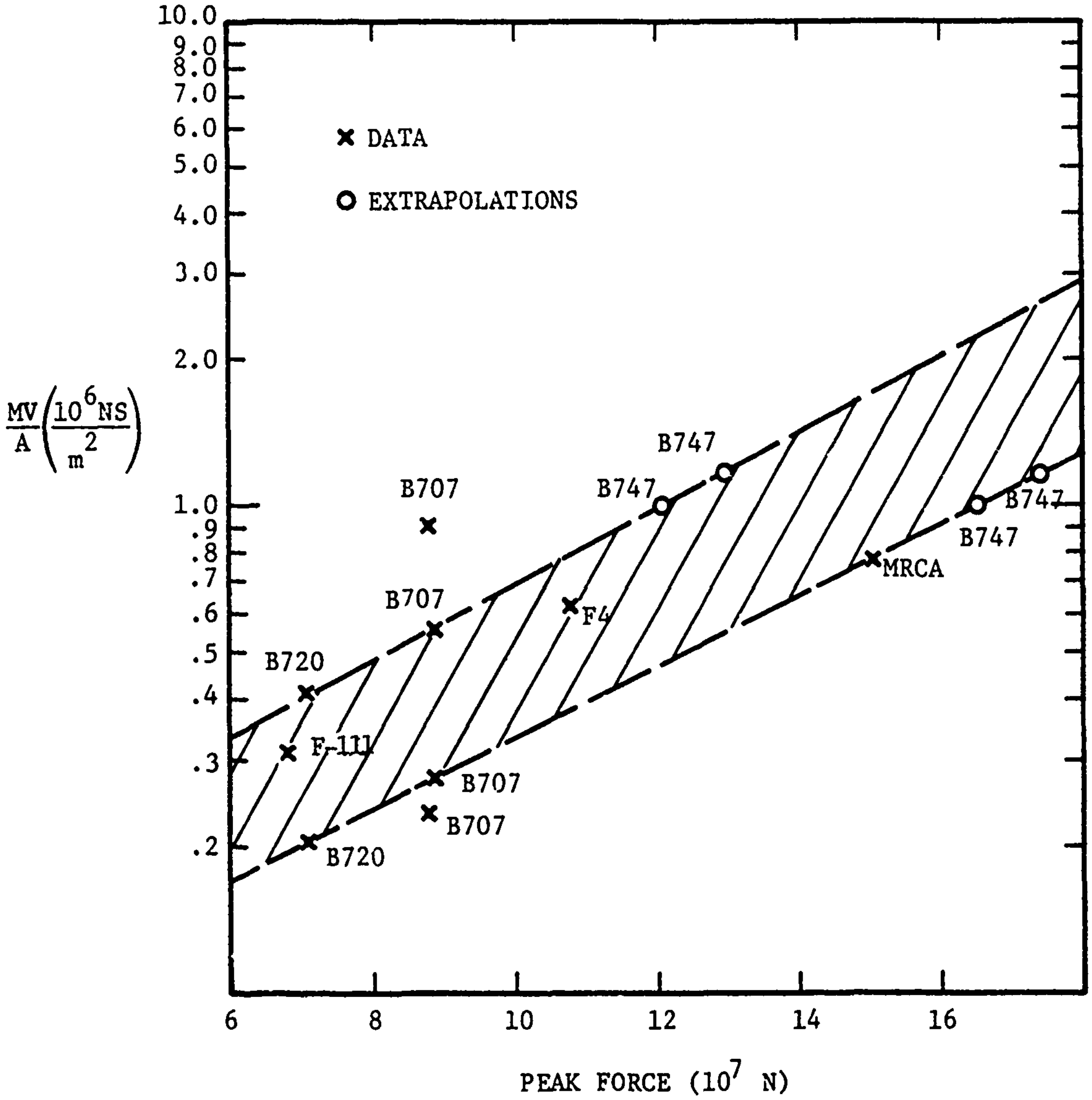


Figure 4-3. Specific Momentum Versus Peak Force

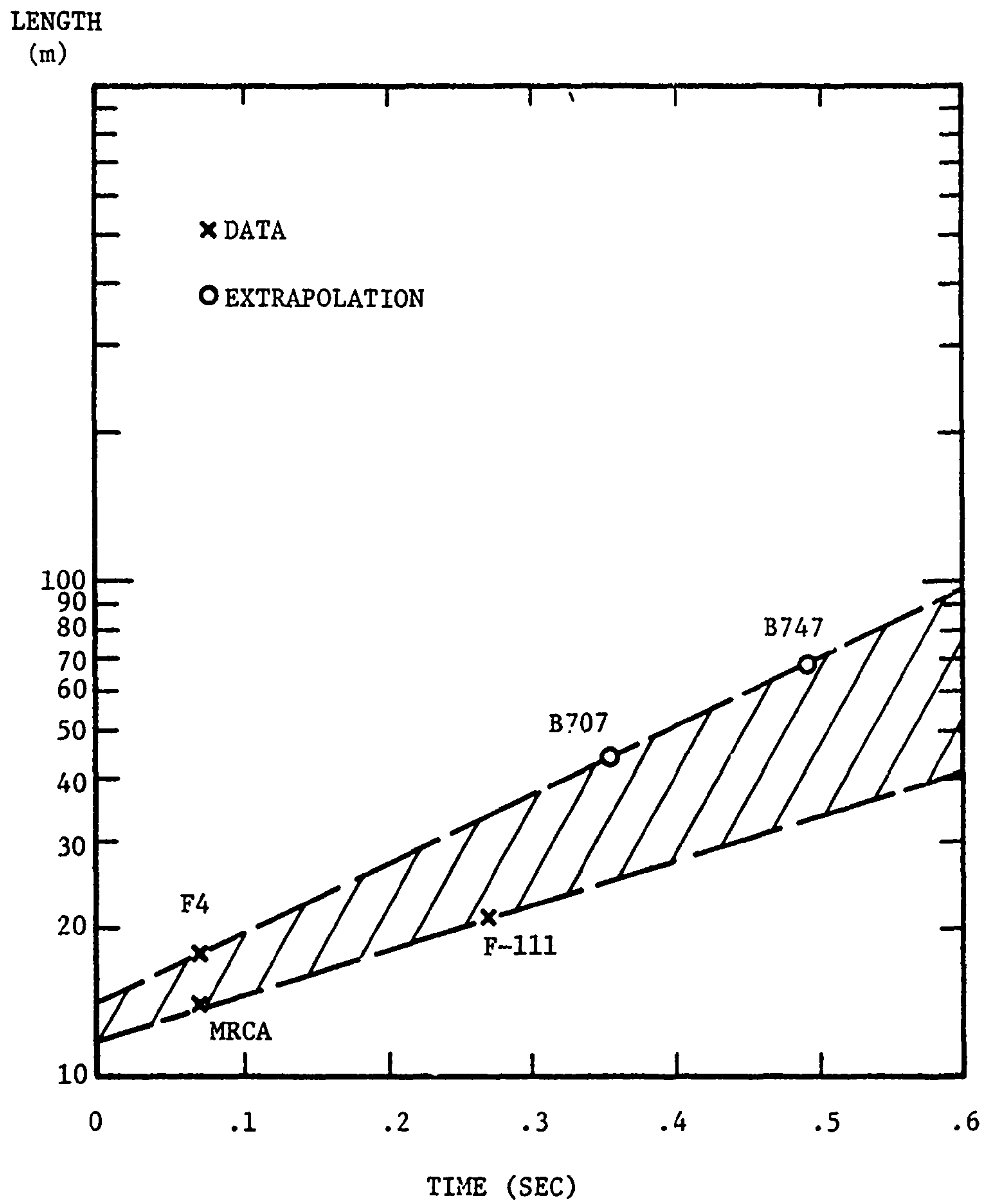


Figure 4-4. Load Durations

Although no direct methods were available for calculating aircraft crash loadings on buried structures, load attenuation through the soil was estimated using a Boussinesq solution for loading at the surface of an elastic half-space (Ref. 4-11). Using a peak stress of 735 psi as derived through modeling techniques described earlier, vertical stress distribution at various depths was determined and is shown in Figure 4-5. Structural loads were proportioned accordingly during design of the superstructure.

4.1.2 General Purpose Bomb

The general purpose bomb taken as a threat to the munition storage weighed 500 pounds and contained approximately 200 pounds of explosive. The analysis concentrated on defining external wall thicknesses required to survive weapon:

- Contact burst
- Near field burst
- Penetration.

Again, both aboveground and buried structures were considered.

Methods to predict breaching radius for a contact explosion are given in Ref. 4-12 based upon the weight of explosive, tamping factor (in air or soil) and a wall material factor. The methods are based upon empirical data gathered during and after World War II and have generally proven conservative for design purposes. Wall thicknesses required to resist breaching were calculated to be:

- Explosion in air - 5.6 feet
- Explosion in soil - 6.8 feet.

Damage producing efficiency drops off drastically as distance between the wall and weapon increases. Data collected during and following World War II for damage to reinforced concrete wall panels were summarized and can be used to determine wall thicknesses required to resist breaching (Ref. 4-13). Using these damage prediction relationships, thicknesses required to resist

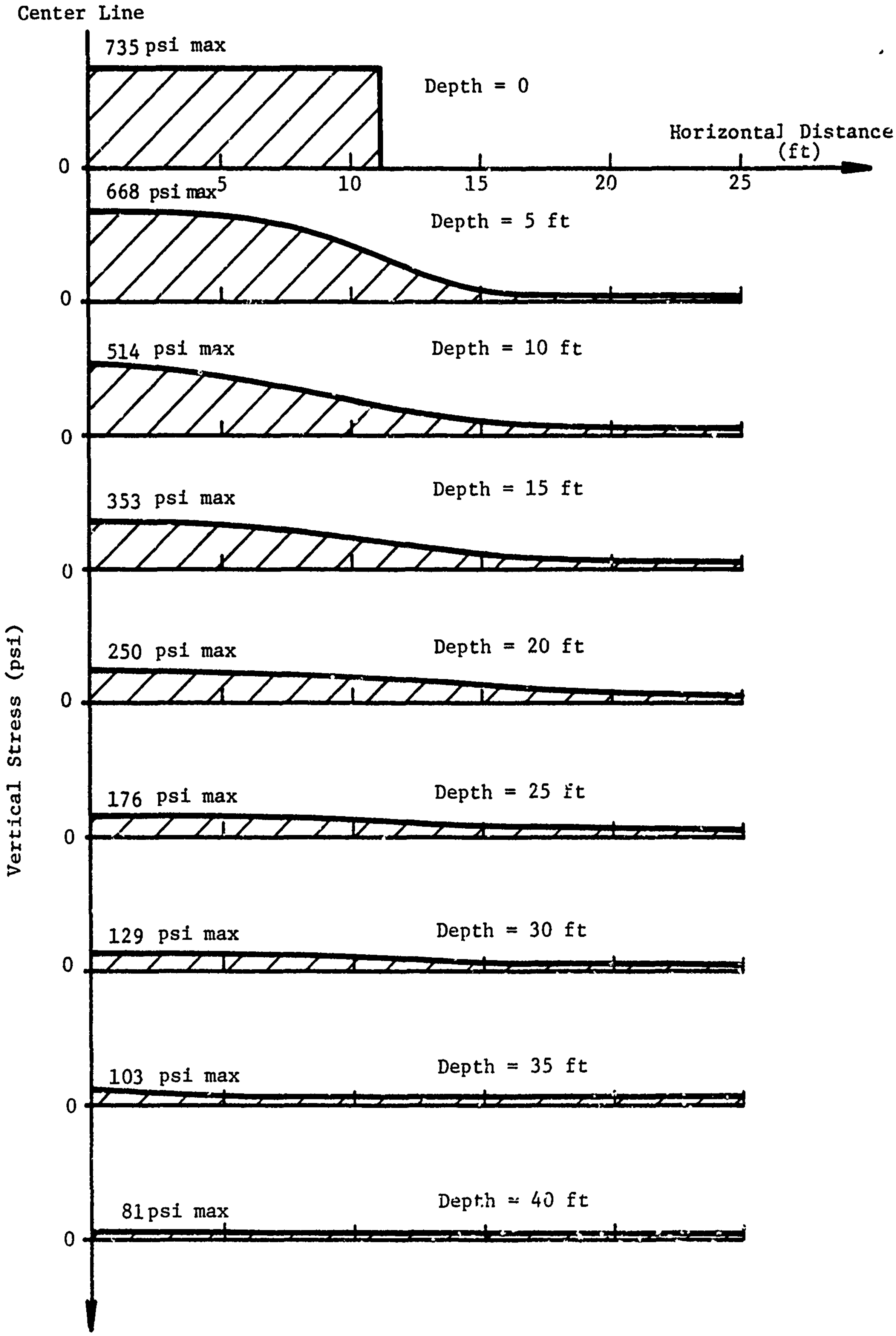


Figure 4-5. Vertical Stress (psi) at Depth

damage from the 500 pound bomb at various standoffs were determined and are shown in Figure 4-6. Recent research by Waterways Experiment Station (Ref. 4-14) and Eglin AFB (Ref. 4-15) has shown that damage to buried structures can be less than would be predicted by earlier procedures. Required thicknesses determined using this later data are also shown on Figure 4-6. Researchers attribute differences to increases in reinforcing steel. Soil property variations can also make significant differences. Each of the prediction methods is based upon spherical charge configurations. Different charge geometries will produce different levels of damages which are not accounted for by current prediction methods. Using data from spherical charges results in conservative designs.

Damage to the concrete roof and walls has been shown to decrease rapidly as the distance between the concrete and explosive source increases. An attractive means of insuring that weapons detonate outside a predetermined distance is to provide a penetration barrier through which the weapon cannot penetrate. Three media were considered for providing a penetration barrier:

- Concrete burster slab
- Rock rubble
- Soil.

An assessment of empirical concrete impact formulas is given in Ref. 4-16. Two methods are presented for determining air-backed concrete thickness required to prevent perforation by cylindrical projectiles. For a 500-pound bomb impacting an air-backed concrete slab as described in Table 4-4, thicknesses required to prevent perforation were:

- NDRC equation - 47 inches
- CEA-EDF equation - 31 inches.

Soil-backed burster slabs will require thicknesses between two feet (penetration into semi-infinite concrete) and the values shown above. If bombs impact air or earth-backed slabs at off-normal angles, weapon defeat is highly probable through either case break-up or explosive deflagration. A two foot thickness for earth-backed slabs is considered adequate.

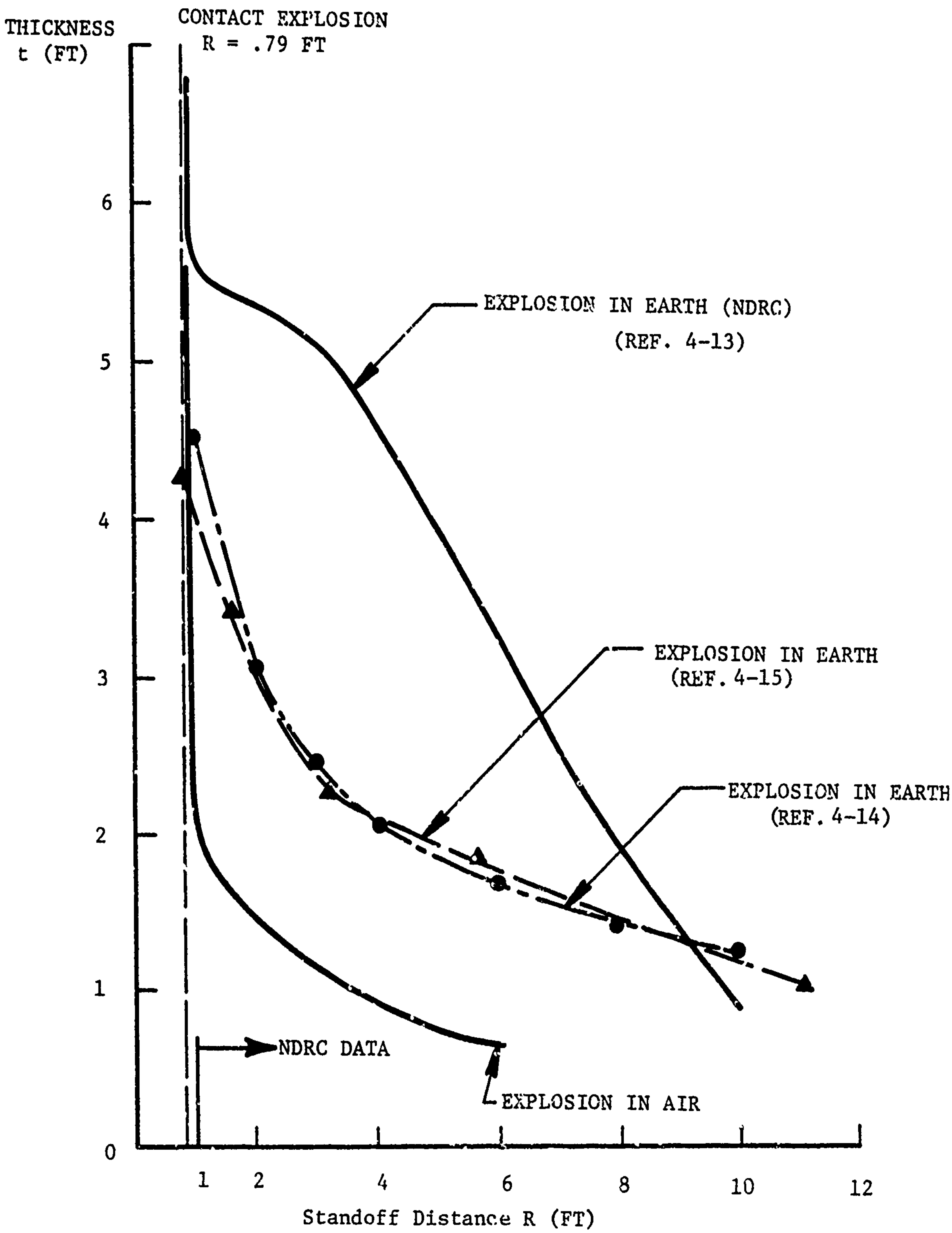


Figure 4-6. Thickness Versus Standoff
(Uncased Spherical Charges)

Table 4-4. Bomb Impact Conditions

Weapon Weight	500 pounds
Weapon Diameter	14 inches
Impact Velocity (Normal Impact)	900 feet per second
Concrete Strength	5000 pounds per square inch (compression)

Research has shown that projectiles encountering at least two layers of rock rubble with diameter at least the same caliber as the projectile have a high probability of being defeated (Ref. 4-17). Projectiles respond as if impacting a semi-infinite mass of the rock. Earlier research at the Colorado School of Mines (Ref. 4-18) developed methods for predicting bomb penetration into rock. Using the Livingston penetration equation for the previously described weapon impacting granite rock, penetration depth of the bomb and layers required to defeat it were calculated as:

- Penetration depth - 20 inches
- Boulder diameter - 14 inches
- Two layers - ≈ 26 inches.

Reference 4-13 also presents graphical solutions to determine penetration depths of bombs and projectiles into soil. Another method for predicting bomb penetration into soil is proposed in Ref. 4-19. Values calculated using the two methods were:

- NDRC method - 15 feet
- Young's equation - 38 feet.

Penetration depth is extremely sensitive to soil properties, and researchers are constantly trying to improve penetration prediction techniques. The two penetration depth values given can be considered as representative of the expected depth. Although adequate for the conceptual designs, more accurate predictions would require specific information on the particular construction site.

4.1.3 Large High Explosive Charge

A 300,000 pound charge (TNT equivalent weight) was specified as a possible threat detonating 100 meters (328 feet) from the munition storage

facility. The charge was taken as detonating tangent to the ground surface. Using methods given in Ref. 3-15, expected blast pressures, impulses, and time durations were calculated. The roof of the structure will be subjected to side-on pressures while walls will experience reflected pressures. Predicted loading parameters are given in Table 4-5. The storage facilities will be designed so that personnel inside the structure will not experience ear or lung damage from the pressures generated by the 300,000 pound explosion.

Table 4-5. Blast Loading Parameters

	Side-On	Reflected
Pressure (psi)	42.0	190.0
Impulse (psi-sec)	1.05	3.29
Time Duration (sec)	0.05	0.035

4.1.4 Chemical Defense

There are continuing indications that the Soviet Union and her Warsaw Pact allies are prepared to use chemical weapons to supplement conventional and/or nuclear warfare operations. In response to this threat, the U. S. forces have in recent years been improving their chemical defense posture to insure that personnel and equipment will be able to survive and function in a chemical warfare environment. One of the critical elements that must survive is the U. S. weapons stockpile. Consequently, the weapon storage sites described in this report have been designed to satisfy this chemical defense requirement.

The following paragraphs address various aspects of the chemical defense issue. First, the chemical agent threat is summarized in Section 4.1.4.1. Design requirements and constraints imposed by this threat are discussed in Section 4.1.4.2. Protection from the chemical agent hazard is accomplished by incorporating a positive pressure collective protection system in the facility. This idea is explored in Section 4.1.4.3 A "don/doff area" must be provided to allow personnel to enter and exit the facility safely without spreading contamination. This is the subject of Section 4.1.4.4.

Finally, Section 4.1.4.5 describes the pressurization requirements needed for the facility. The following discussion is general in the sense that it can be applied to any weapon storage facility layout under consideration. Implementation in six specific layouts is discussed later in Section 5.3.

4.1.4.1 Chemical Agent Threat

The chemical warfare agents of interest for this program may be classified according to their physiological action as:

(1) Nerve agents
(2) Blister agents
(3) Blood agents
(4) Choking agents
(5) Tear agents
(6) Vomiting agents.

The first four types are considered to be toxic agents, while the last two are generally regarded as incapacitating agents.

Nerve agents act by upsetting the balance between the sympathetic and parasympathetic nervous systems, resulting in convulsions, coma, and death. Blister agents cause severe nose and throat irritation, eye damage, and skin blistering and swelling. When death occurs, it is usually the result of infection. Blood agents prevent transfer of oxygen from the blood to the body tissue resulting in death due to interference with the liver, kidneys, and lungs. Choking agents cause irritation and swelling of nose and throat membranes. Death occurs from lack of oxygen. Appendix 2 summarizes data on the toxic chemical warfare agents, and cites references for more detailed information.

There are numerous specific agents within each of the broad classes described above. Table 4-6 shows the lethal doses for some of these. Even sub-lethal doses can have very serious and lengthy incapacitating effects (see Appendix 2). The fact that incapacitating dosages are extremely low (e.g., $4 \mu g/cm^2$ for agent VX) means that an extremely efficient and reliable

Table 4-6. Chemical Agent Lethal Doses

Agent	Exposure Conditions	Median Lethal Dosage ($mg\text{-}min/m^3$)
Blister Agents		
• HD distilled mustard	Inhalation	1,500
	Skin absorption	10,000
• HN-3 nitrogen mustard	Inhalation	1,500
	Skin absorption	10,000 (est)
• L lewisite	Inhalation	1,200-1,500
	Skin absorption	100,000
Nerve Agents		
• GA tabun	Inhalation (resting)	400
• GB sarin	Inhalation (resting)	100
	(mild activity)	70
• GD soman	Inhalation (resting)	GB-GA range
Blood Agents		
• AC hydrogen cyanide	Inhalation	Wide variation with concentration γ
		2,000 for $\gamma = 200\ mg/m^3$
		4,500 for $\gamma = 150\ mg/m^3$
• CK cyanogen chloride	Inhalation	11,000
• SA arsine	Inhalation	5,000
Choking Agents		
• CG phosgene	Inhalation	3,200
• DP diphosgene	Inhalation	3,200

Source: Ref. 4-20

air filtration system will be needed to protect personnel inside the weapon storage facility. As shown in Table 4-6, the agent threat includes both liquid and vapor hazards, further complicating the filtration system design.

4.1.4.2 Requirements/Constraints

The type of chemical defense system selected for the weapon storage facilities was dictated in large part by the following five performance requirements established by the Government sponsor at the start of the program.

(1) Chemical protection must extend to the weapon storage and handling areas as well as to all personnel areas, i.e., facility personnel must be able to work in a "shirtsleeve" environment (without protective clothing) in all inside areas of the facility during and after a chemical agent attack.

(2) The chemical defense system for the facility must not be vulnerable to the internal or external explosion hazards or terrorist threats described in Section 4.1.

(3) Facility personnel must be able to loadout weapons in a chemical warfare environment without contaminating the interior of the facility.

(4) There are no time constraints placed on weapon loadout operations in a chemical attack environment.

(5) The facility will not be required to accept additional weapons for storage while the outside environment is contaminated.

The approach selected by SwRI to meet these requirements was to design the weapon storage facility as a positive pressure collective protection facility. Several groundrules and assumptions were established by SwRI in order to insure the feasibility of this approach:

(1) The chemical agent threat is strictly external
   (a) Chemical weapons will not be stored inside the facility
   (b) Traitorous acts by "friendly" personnel inside the facility will not be considered.

(2) All fresh air entering the facility will pass through the chemical defense system before entering the facility air conditioning, heating, and ventilation system.

(3) Air leakage will be strictly controlled and kept to a minimum.

(4) Electrical power (primary or backup) will always be available

(5) State-of-the-art chemical agent sensors are not reliable enough, and airflow damper control systems are not fast enough; therefore, the chemical agent filtration system will be required to operate continuously in a wartime environment.

(6) The facility must be able to receive a resupply of chemical agent filters while the outside environment is contaminated.

(7) Facility personnel (in protective clothing) must be able to changeout spent filters without compromising or interrupting the chemical warfare protection of the facility.

(8) Provisions must be made for personnel entry/exit while the outside environment is contaminated.

(9) Equipment decontamination will be accomplished elsewhere. No facilities will be provided for this role.

The need for, and impact of these assumptions will become apparent as the design and operation of the chemical protection system is explored in the following sections of the report.

4.1.4.3 Collective Protection

Protection from the chemical agent threat is accomplished by incorporating a positive pressure collective protection system within the storage site. A collective protection shelter is defined as an enclosure within which personnel can work safely without having to wear individual chemical defense clothing and equipment. This is accomplished by keeping the air pressure inside the shelter higher than that of the ambient outside air pressure, and by filtering the air supplied to the shelter to remove chemical warfare agents.

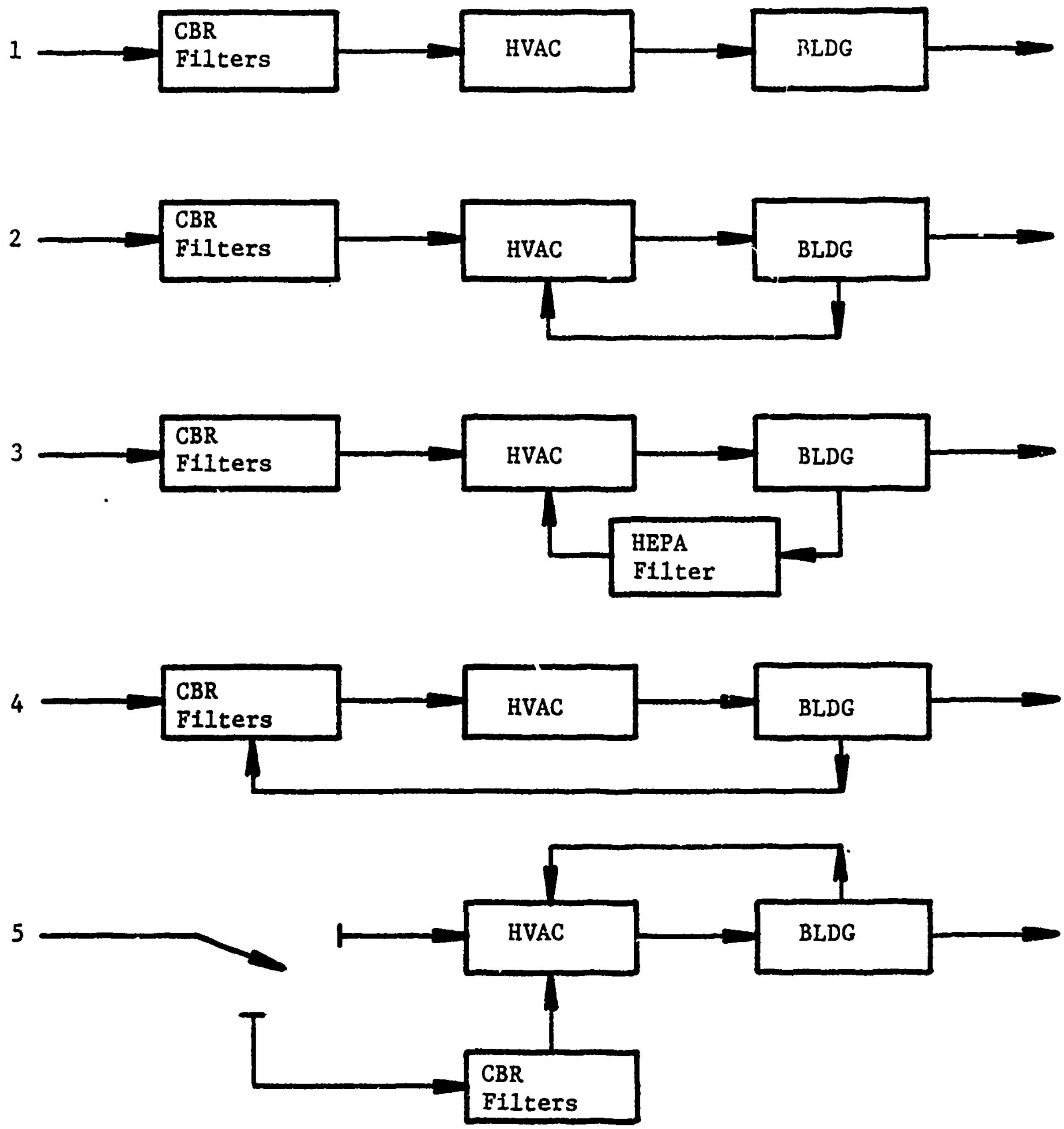
Five options were considered for supplying clean air to the facility. These options are illustrated in Figure 4-7 and discussed below:

(1) Blowthrough system with no recirculation. Air from the outside is passed through chemical defense filters to the heating, ventilating, and air conditioning (HVAC) system for the facility. All return air is then exhausted to the outside. The primary disadvantage of this option is that the HVAC system must be large relative to other options because it must continuously condition fresh air from the outside. The main advantage is a simplistic duct network since no recirculation must be provided.

(2) Recirculation through HVAC only. Similar to option 1 except that some percentage (e.g., 80 percent) of the exhaust air is recirculated through the HVAC system. This reduces the load on the HVAC system since the recirculation air is already conditioned to a large extent. Care must be taken to provide sufficient cleansing of odors picked up by the recirculated air.

(3) Recirculation through HVAC and a particulate filter. This option is identical to option 2 except that high efficiency particulate air (HEPA) filters are added in the recirculation air loop. The HEPA filters will help clean the air of dust, debris, and any radioactive particles generated from an accidental explosion in the weapon bays. The primary disadvantages are the additional costs and maintenance actions associated with HEPA filters.

(4) Recirculation through CBR filters and HVAC. In this option, the recirculation air is passed back through the chemical/biological/radiological filters before being recirculated through the HVAC system. The advantage to this approach is that the effects of a saboteur using chemical agents inside the facility would be minimized. A disadvantage is that the airflow will be heated by 10 to 15 degrees during each pass through the CBR filters (Ref. 4-21) thus placing an added burden on the environmental control system.



CBR = Chemical/Biological/Radiological

HVAC = Heating/Ventilating/Air Conditioning

HEPA = High Efficiency Particulate Air

Figure 4-7. Air Supply Options

(5) Flow through CBR filters only when attacked. A damper is used to control inlet airflow so that the CBR filters are inline only during an actual chemical agent attack. Under normal operating conditions, inlet air bypasses the CBR filters and flows directly to the HVAC system. An advantage is the longer life of the CBR filter components. A disadvantage is reliance on chemical sensors and fast-acting damper networks.

It was not considered cost effective to size an air handling system that operated without recirculation, so option 1 was discarded. The high reliability and fast reaction of sensors and dampers needed for option 5 led to its rejection. A decision to not consider the threat of an internal saboteur led to the deletion of option 4. The remaining options 2 and 3 are very similar. Option 3 was selected since there is some slight threat of airborne radioactive particles being released following an accidental explosion involving the stored weapons. The following paragraphs describe the CBR filter system. The HEPA filter network is described in Section 5.3.

A typical chemical defense filter system is illustrated in Figure 4-8. It consists of the following components: (1) damper, (2) vaneaxial type blower, (3) inlet air plenum chamber, (4) glass fiber type prefilter, (5) pleated fiber bed HEPA filter, (6) charcoal gas adsorption filter, (7) exhaust air plenum chamber, and (8) flexible interface hoses. This type of filter unit is typical of those currently in use by the Army at large permanent collective protection facilities available for use by key national political and military personnel.

The fibrous bed of the prefilter is designed to have a 75 - 80 percent collection efficiency for large particles with diameters in excess of 1 to 2 microns. The purpose of the prefilter is to protect the downstream HEPA filter from excessive particle loads in the airstream. The HEPA filters are constructed with pleated fiber beds designed to have a 99.97 percent collection efficiency for 0.3 micron particles. Airborne biological and radiological contaminants will be collected by the HEPA filter. These filters are very similar to the ones used for particle collection in nuclear power plants.

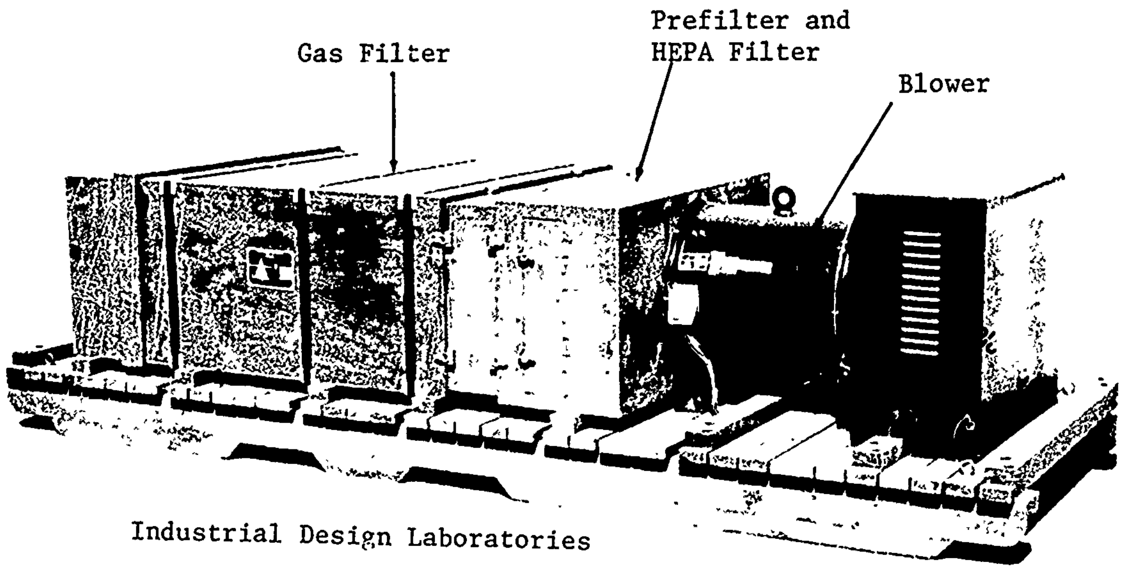


Figure 4-8. Typical Chemical Defense Filter System

The gas filter portion of the system consists of activated charcoal that has been impregnated on the surface with copper, silver, and chromium salts (referred to as ASC Whetlerite charcoal). Figure 4-9 illustrates the flow pattern in a typical gas filter. The impregnated charcoal adsorbs and/or chemically neutralizes nerve, blood, blister, and choking agents used in chemical warfare. The charcoal filter illustrated in Figure 4-9 is the type currently in use by the Army. An alternate configuration that could be used is shown in Figure 4-10. This charcoal filter is the industry standard for use in nuclear power plants. If filled with Whetlerized charcoal instead of plain activated charcoal, it would then be acceptable for chemical defense purposes. Table 4-7 provides a comparison of the physical characteristics of the two types of gas filters. Government specifications require that the gas filter be able to provide at least a 10^5 reduction in concentration when exposed to the chemical warfare agents described in Section 4.1.4.1.

The proper arrangement of the components of the air handling and filtering system is critical if chemical protection is to be achieved. Several layouts were evaluated as shown in Appendix 2, but only one arrangement precluded the formation of any potential chemical agent leak paths into the protected area. This configuration is illustrated in Figure 4-11. The blower must be located upstream from the filters and from the protected area in order for the system to work safely. The blower will then keep a positive pressure on the filters, the air ducts, and the weapon storage facility. Areas at positive pressure are marked with a + in Figure 4-11. It is not possible for contaminated ambient air to bypass the filters and enter the airstream through cracks in the ducts since the clean air in the ducts is at a higher pressure. Similarly, contaminated ambient air cannot pass through the wall penetration connecting the CBR filters to the HVAC system because the air inside the storage facility is at a positive pressure with respect to ambient.

As indicated in Figure 4-11, the blower, the filter components, and the room they are located in will be contaminated since the airstream does not become safe until after it passes through the final charcoal beds in the

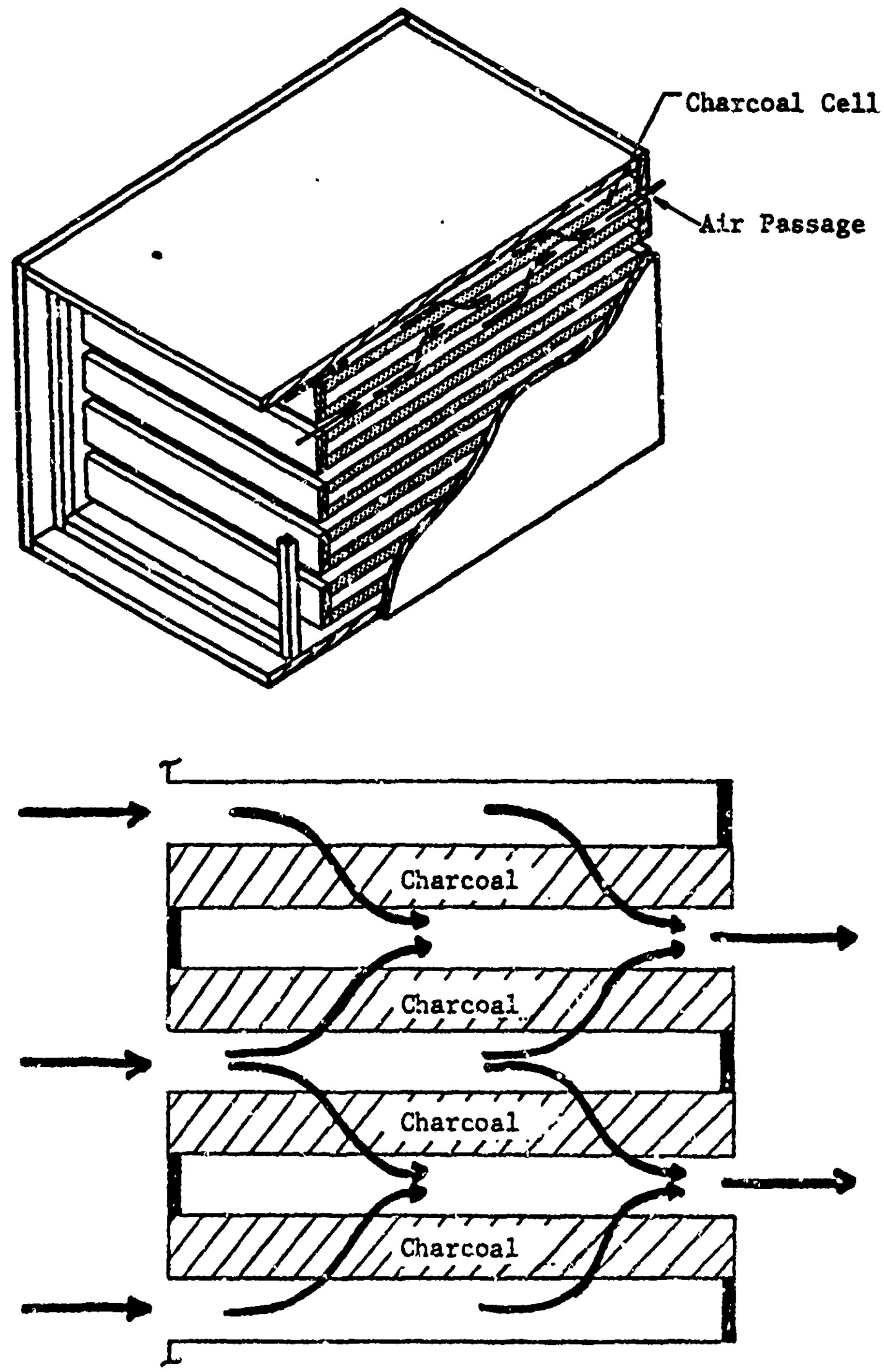


Figure 4-9. Current Army Gas Filter for Collective Protection Structures

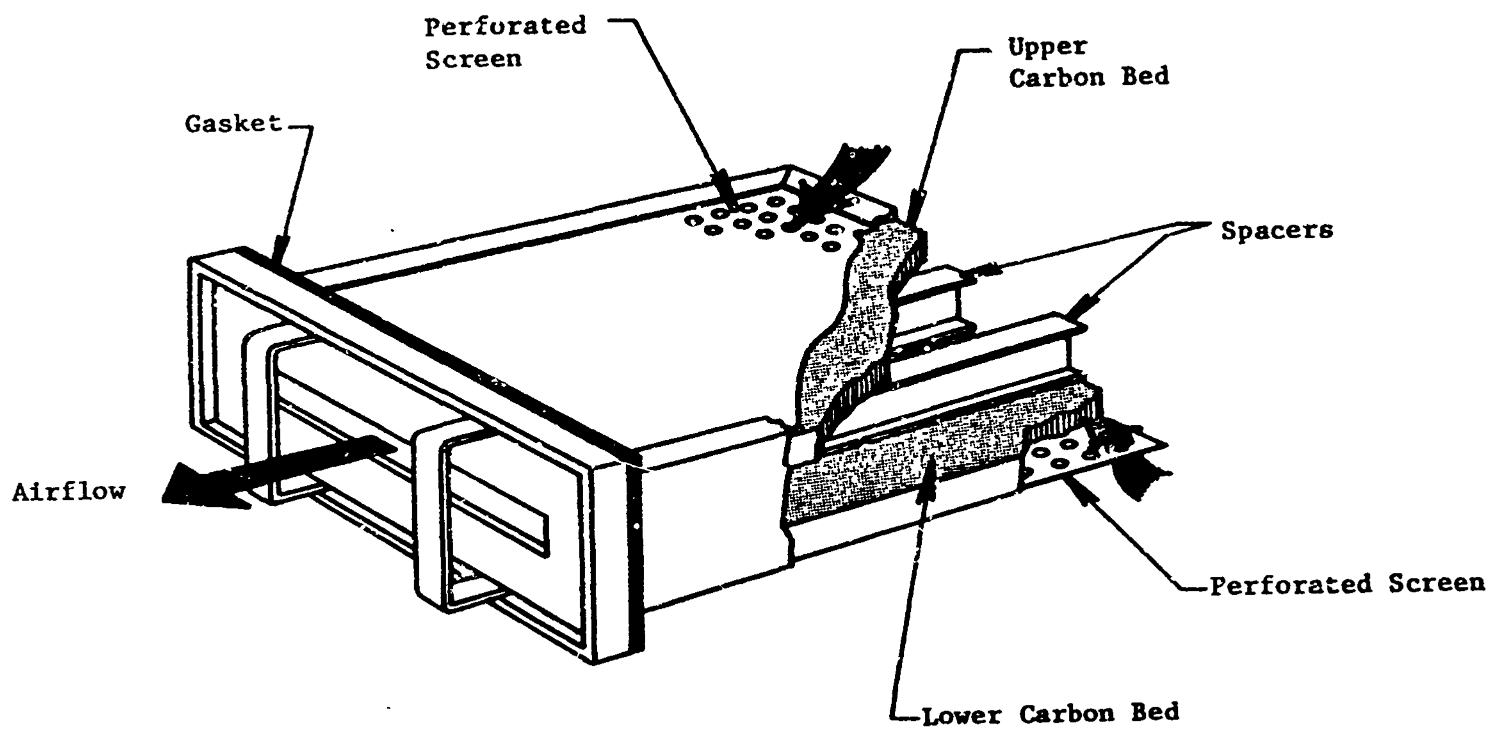


Figure 4-10. Tray-Type Gas Filter

Table 4-7. Gas Filter Characteristics

	Army Gas Filters		Nuclear Power Industry Filter
Flow rate (CFM)	2500	5000	330
Dimensions (inches)	48 x 26 x 52	48 x 48 x 51	30 x 6 x 24
Weight (pounds)	1000	2100	105
Number charcoal beds	10	20	2
Charcoal bed depth (inches)	1.13	1.13	2.00
Air resistance (in. H_2O)	1.25	1.25	1.15
Construction materials	wood	wood	steel
Refillable	no	no	yes

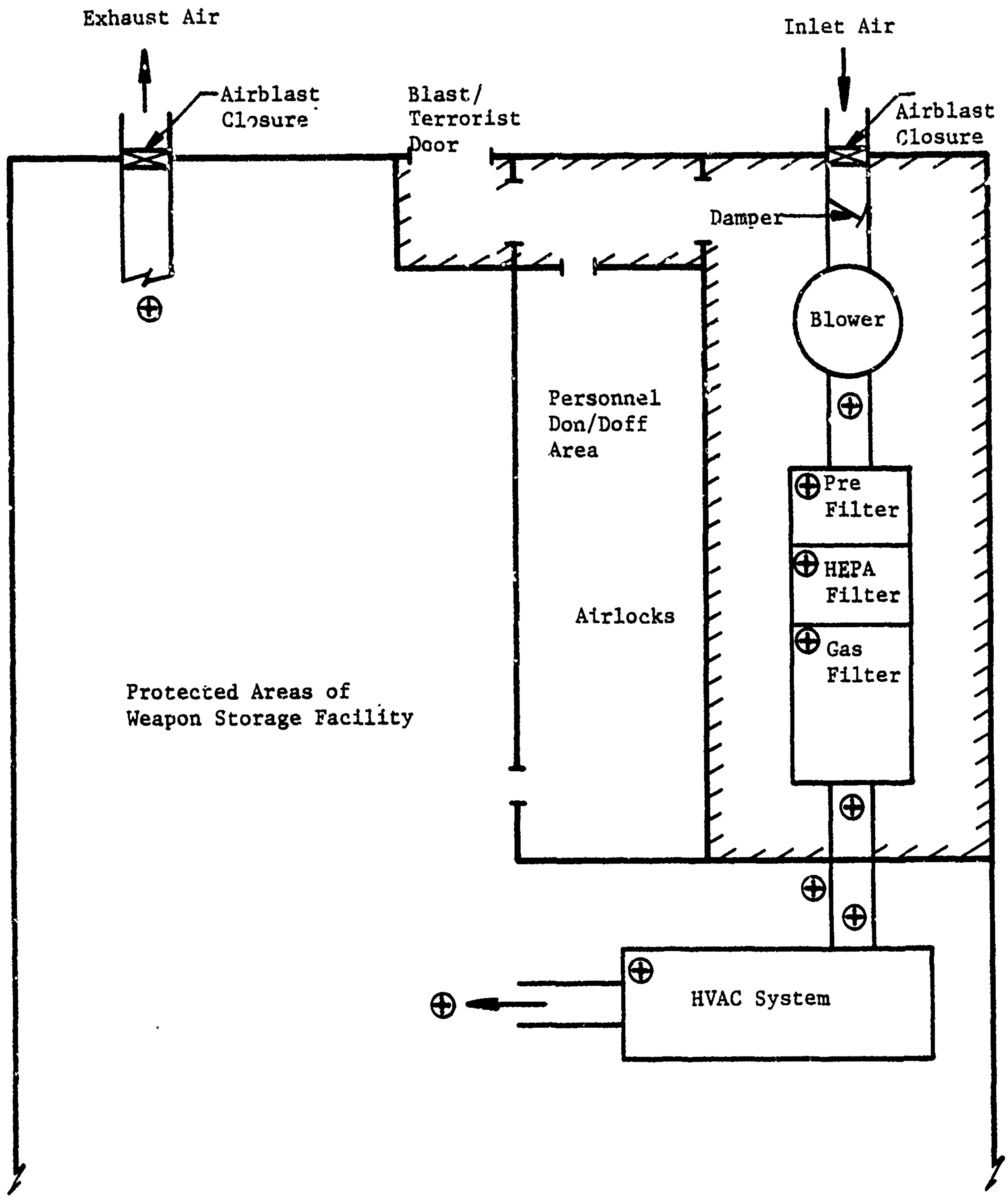


Figure 4-11. Typical Positive Pressure System for Collective Protection

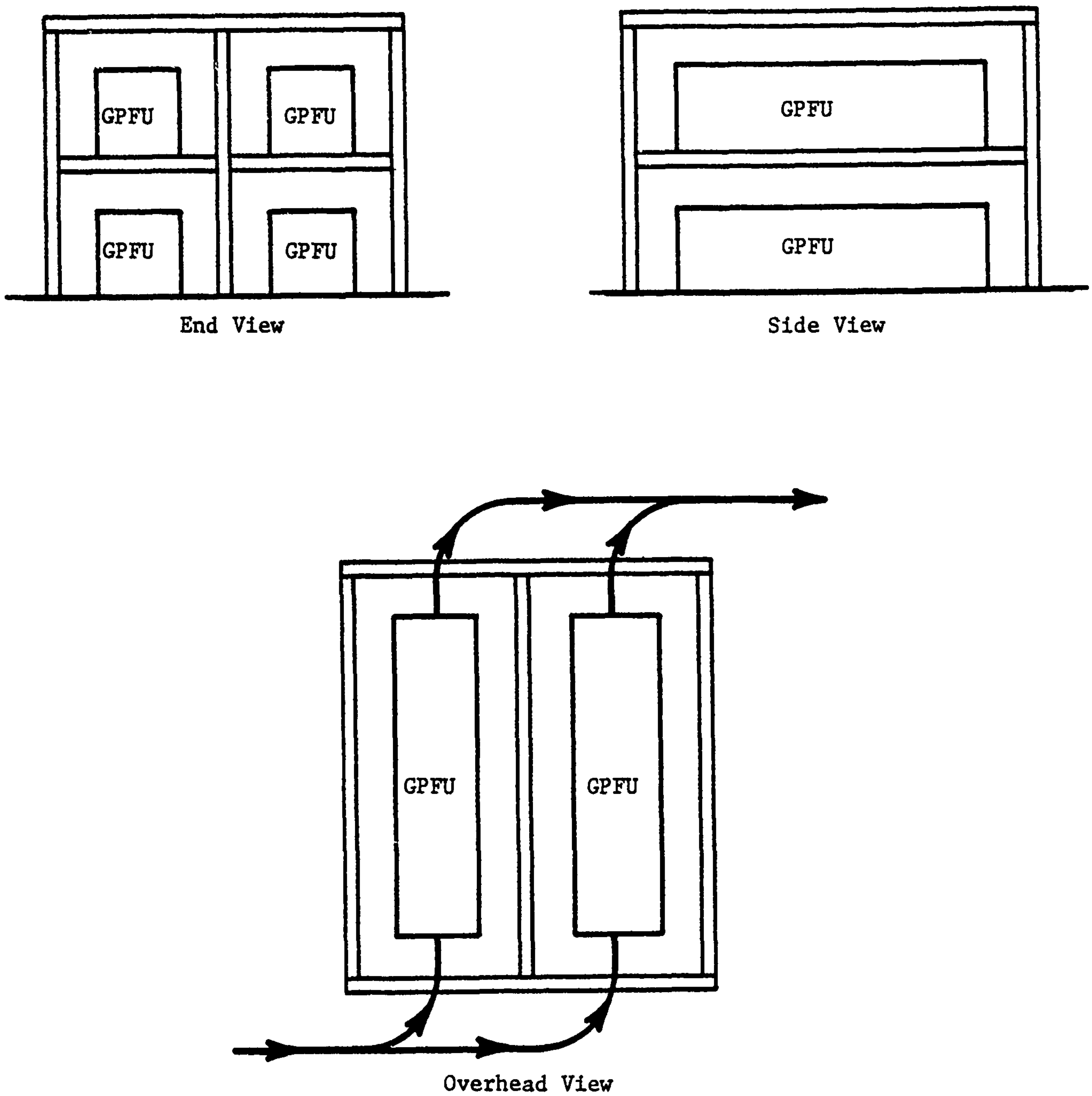
gas filter. Consequently, this filter room must be completely sealed from the protected area. Filter changeout must be accomplished by personnel wearing protective clothing. Personnel entry to and exit from the protected area must be through a specially designed "don/doff" area containing airlocks and provisions for handling contaminated clothing. Details of this area are provided in later paragraphs.

Pressure control will be accomplished by pressure sensors that drive airflow dampers in the ducts. An airblast closure must be located in the inlet air and exhaust air stacks. The closure mechanism will be activated by the overpressure pulse generated by an external explosion, thus closing off the airduct and preventing the pressure pulse from damaging the air handling system in the facility.

Most of the storage facility layouts draw approximately 7500 CFM of outside air to provide for pressurization, ventilation, intake for generators, and leakage. The chemical defense filter unit pictured earlier in Figure 4-8 has a rated capacity of 5000 CFM. Consequently, two such units must be kept on-line at all times. Four units have been provided at each facility, with two on-line at any given time. Figure 4-12 shows the filter system arrangement. Dampers in the air ducts are used to direct the flow either through the top tier or the bottom tier of filters. With this configuration, spent filters can be changed without interrupting the pressurization of the facility or the filtration of the intake air.

4.1.4.4 Individual Protection

While personnel are inside the weapon storage facility they will not need to wear chemical defense clothing. It is assumed, however, that there will be occasions when it may be necessary for personnel to leave and reenter the shelter while the outside area is contaminated. Examples of such instances would occur during weapon loadout or during filter changeout. Consequently, a supply of chemical defense ensembles must be available to personnel in the facility, and provisions must be made for removing ("doffing") contaminated ensembles before entering the facility. The standard U.S. Army chemical defense ensemble has been assumed for this analysis (see Appendix 2).



GPFU = Gas-Particulate Filter Unit, Skid-Mounted

Figure 4-12. Filter Unit Installation

A "don/doff" area has been designed to facilitate the entry/exit process. The layout of this area is shown in Figure 4-13. It is basically split into two halves, one for entry and one for exit. Suggested procedures for processing through the don/doff area are explored in detail in Appendix 2. Only a summary is provided here.

Personnel entering the facility from a contaminated area will be wearing the chemical defense ensemble. As they pass through the rooms shown in Figure 4-13, the pieces of the protective suit are systematically removed in such a way as to preclude contaminating the individual. The first room (labeled liquid hazard area) is used to remove the outer layers of clothing that may contain liquid droplets. The second room (labeled vapor hazard area) is at a slightly higher pressure than the first to keep liquid agents from entering the room via entrainment. The charcoal impregnated undergarments are removed in the vapor hazard area. As the person enters the airlock, the chemical mask is exchanged for a clean one. The person remains in the airlock at least two minutes to allow purging air to reduce the concentration of any remaining chemical vapors. The remainder of the protective clothing is removed in the undress room, where the air pressure is slightly higher than in the vapor hazard area. As a final precaution, a thorough shower is taken before dressing in normal work clothes.*

The procedure for donning the protective ensemble is the reverse of the doff procedure, except that the shower phase is removed. During doff, the emphasis was on protecting bare skin from contact with contaminants on the suit. When donning a clean suit, the emphasis is on ensuring that all ensemble components are sealed properly with no snags, tears, or punctures. To help enforce proper entry and exit procedures, the rooms used for entry are separated by a wall from the similar rooms used for exit. A special door that can only be opened from the correct side is placed on the last room (exit end) of each of the two paths to prevent people from going the wrong direction through the facility. Contaminated clothing is passed through

* There is some disagreement within the chemical defense community regarding the value of the shower phase of the doff procedure.

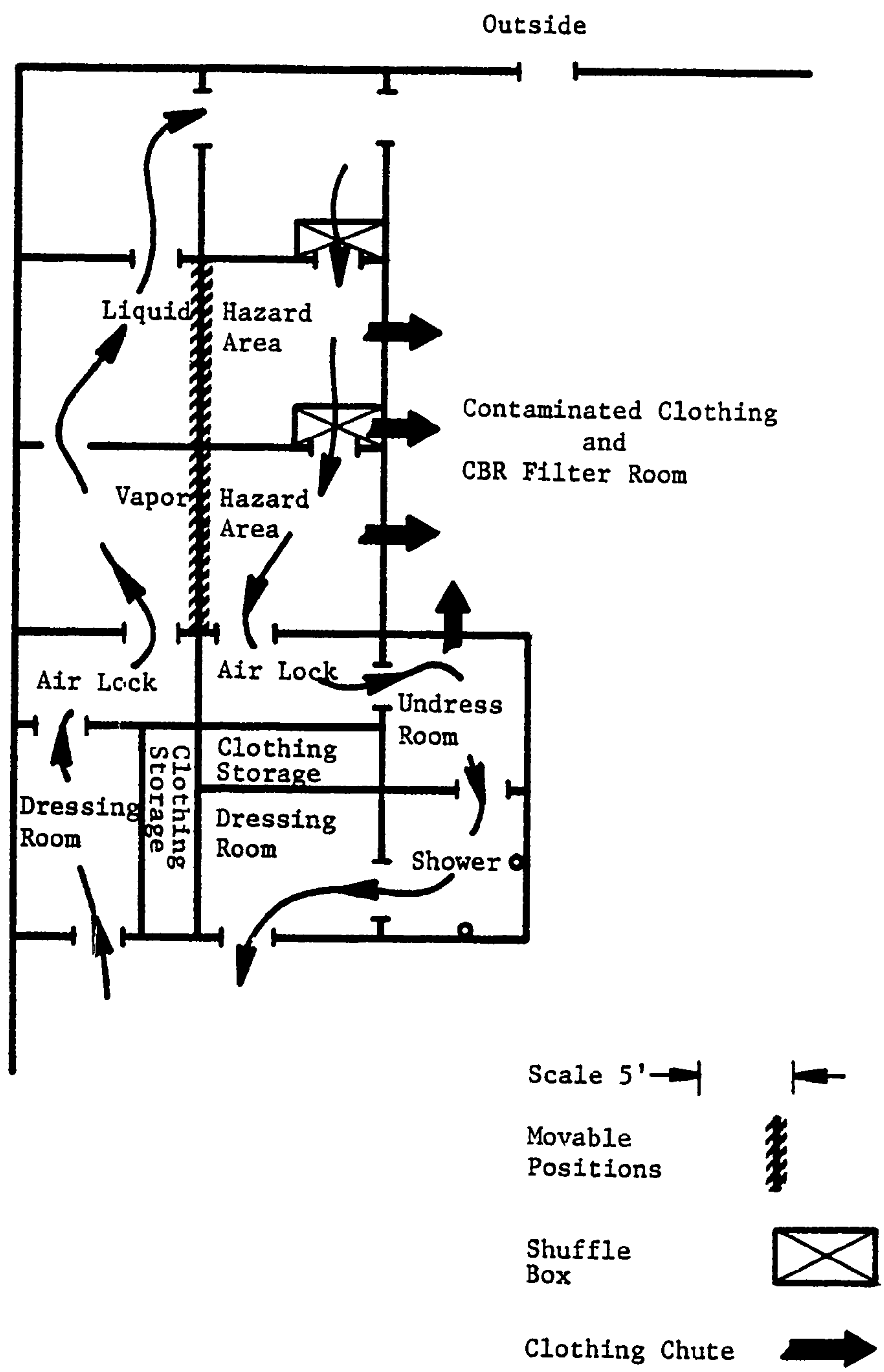


Figure 4-13. Don/Doff Facility Layout

a specially designed chute to the filter room for disposal. Similar chutes are used in industry and are readily available.

No provisions have been made for decontaminating items of equipment. It is assumed that the military units in the vicinity will have vehicle and equipment decontamination stations set up that can be used if necessary. Once a vehicle (e.g., forklift) is taken into the contaminated environment, it will be left there. Personnel entering through the don/doff area will not be allowed to bring in any personal articles (e.g., pencils, watches, clipboards, etc.) that may have been exposed to chemical agents.

4.1.4.5 Pressurization Requirements

Table 4-8 shows the pressurization requirements that have been selected to make the weapons storage facility function properly as a positive pressure collective protection facility. The building interior is maintained at 0.3 inches of water (0.011 psi) above ambient outside pressure. This pressure level is decreased in increments through the don/doff area until ambient pressure is reached outside the liquid hazard area. The CBR filter room is also at ambient pressure.

The volumetric flow rate required to maintain the 0.3 inches of water positive pressure gradient in the building ranges between 3500 and 4500 CFM, depending on the layout and the leakage rate of a given storage site concept. The two airlocks in the don /doff area each require an airflow sufficient to give a 1000:1 reduction in contaminant concentration in two minutes. This equates to a volumetric flow rate of 1730 CFM through each airlock. A 2200 CFM flow through the undress area is used to achieve the same air dilution results in this section. Appendix 2 documents the pressurization and airflow calculations.

All outside air pulled into the facility will first pass through the CBR filter system. The HVAC system will then condition and distribute the filtered air throughout the facility. A large percentage of the return air

Table 4-8. Facility Pressurization Requirements

Location	Pressurization Level In. of H_2O	Pressurization Level psi
CBR Filter Room	0.0	0.000
Loading Dock	0.0	0.000
Don/Doff Liquid Hazard Area	0.15	0.005
Don/Doff Vapor Hazard Area	0.20	0.007
Don/Doff Airlocks, Undress Area, Shower	0.25	0.009
Don/Doff Dressing Area	0.30	0.011
Main Corridors	0.30	0.011
Weapon Storage Bays	0.30	0.011
Maintenance Bay	0.30	0.011
Control Room	0.30	0.011
Support Areas (Mech, Elec, Stg, etc.)	0.30	0.011

will be recirculated through the HVAC system. The remainder will pass through the don/doff area to produce the cascading pressure levels needed there, and will then be vented to the outside. Pressure sensors and automatic dampers will be used throughout the site to monitor and control the positive pressure.

Some consideration was given to the possibility of wind gusts "overpowering" the shelter pressurization level and allowing contaminants to be blown into the building through doors or outside air ducts. A 25 mph wind gust generates a dynamic pressure of approximately 0.3 inches of water (0.011 psi). As the storage facility layouts were finalized, it became apparent that none of the building openings would possibly be exposed to wind gusts of this level. Consequently, no increase was made in shelter pressurization levels to overcome this effect.

4.1.5 Terrorist

Introduction

The storage concepts were designed to survive the loadings which result from prescribed threats. These threats included a 747 impact; a 500-pound bomb; a 300,000 pound charge detonated at 100 meters; and chemical agents.

The proposed designs were then evaluated to determine their resistance to terrorist attack. By following this procedure, it was possible to optimize designs for the given threats. Subsequent evaluation of a structure's resistance to subversive groups permitted the determination of "weak" points as well as the time required to penetrate a structure. This section includes a technical discussion on the terrorist threat. The evaluation of the six concepts for these technical considerations is presented in Section 5.5.

Scenarios

Preliminary scenarios were hypothesized strictly in terms of weapons which might be employed against a structure. Logistical problems, such as

the number of men required were not addressed. The weapons and tools initially considered include:

- sledgehammers
- bolt cutters
- diagonal pliers
- punchers
- gas-powered saws
- wrecking bars
- drills
- splitting mauls
- battering ram
- jack hammer
- recoilless rifles
- small arms
- oxy-acetylene torch
- explosively driven flyer plates
- shaped charges
- burning bars
- bulk high explosives (HE).

The usefulness of each of these items against the proposed designs was evaluated qualitatively. Flyer plates, shaped charges, burning bars, and bulk HE were determined to constitute the primary threats.

Each of these primary threats was then considered quantitatively. The postulated scenarios involved using a single flyer plate, shaped charges, or detonation of bulk HE to breach the concrete wall or roof. The exposed rebars could then be cut with a burning bar. Limiting the scenarios to one or two attempts to breach the concrete resulted in large, awkward weapons for the flyer plate and shaped charge attacks.* Therefore, only the scenario utilizing bulk HE to breach the concrete, and using burning bars to cut the exposed rebars was considered further.

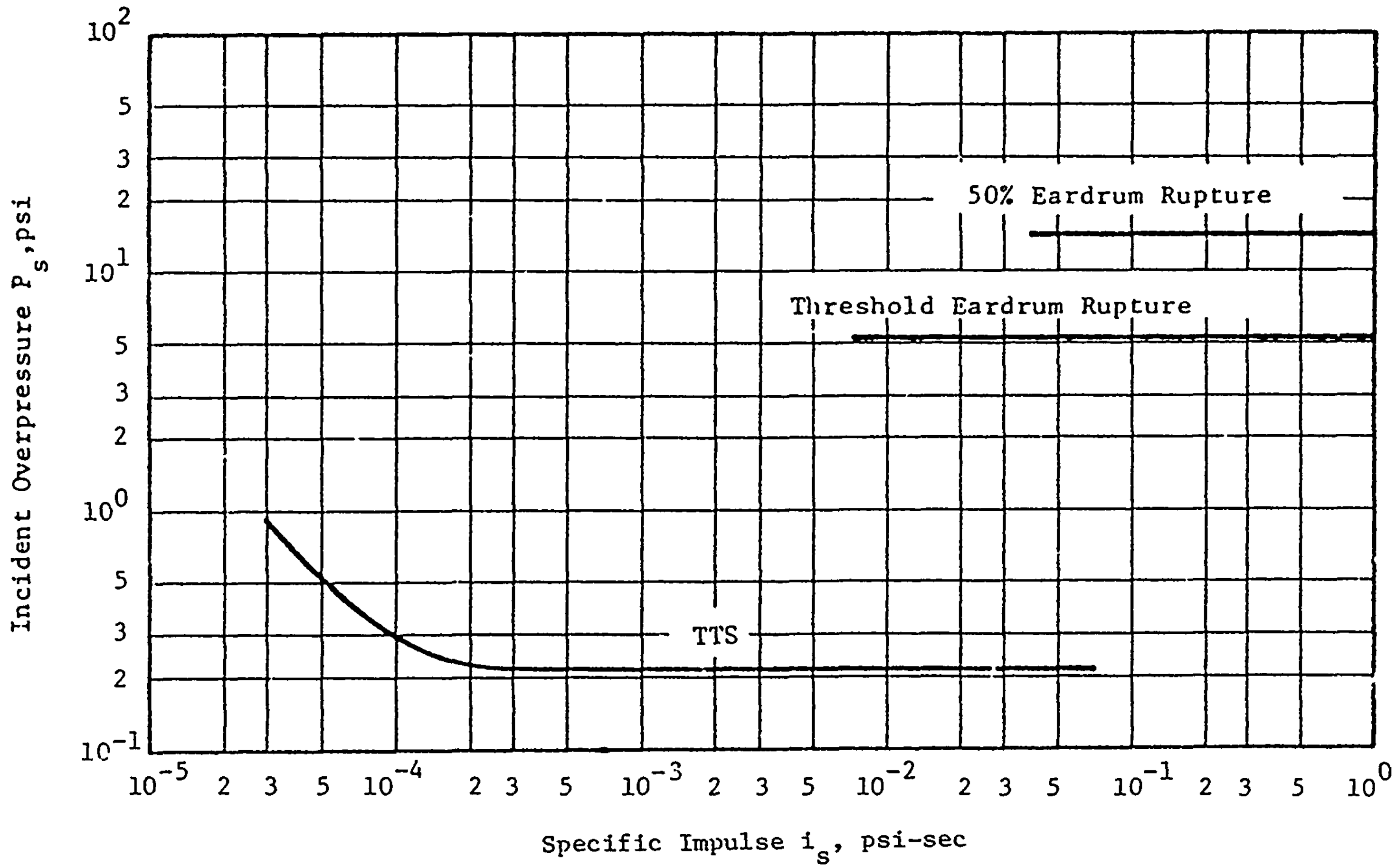
* Assumed from outset that time would permit no more than two explosive charges or devices.

For a given reinforced concrete wall, Table 4-9 (Ref. 4-22) can be used to determine the quantity of TNT required to breach the wall. The breaching radius is approximately equal to the wall thickness.

Table 4-9. Breaching Charges for Reinforced Concrete

THICKNESS OF CONCRETE IN FEET	POUNDS OF TNT REQUIRED TO BREACH REINFORCED CONCRETE WALL			
		(TAMPED) 		(TAMPED) 
1	5	5	5	5
2	22	8	28	16
3	52	21	67	41
4	124	49	159	88
5	219	79	282	157
6	378	135	486	270
7	517	185	663	369
8	771	276	991	551
9	1098	392	1411	784
10	1505	540	1935	1075

Prior to detonation of a breaching charge, terrorists must retreat to a location where the probability of injury is reduced. The standoff required for a given quantity of explosive can be bounded by considering the probability of ear damage and lung damage as a result of blast overpressures and impulses. Figure 4-14 shows isodamage curves for human ear damage and Figure 4-15 depicts similar curves for lung damage. It is anticipated that terrorists would move farther than the distance required to experience a pressure that would cause eardrum rupture to an unprotected ear. They would be expected to move a minimum distance from the charge which would place them at the threshold for lung damage. Figures 4-14 and 4-15 were extracted from DOE/TIC 11268 (Ref. 3-15).

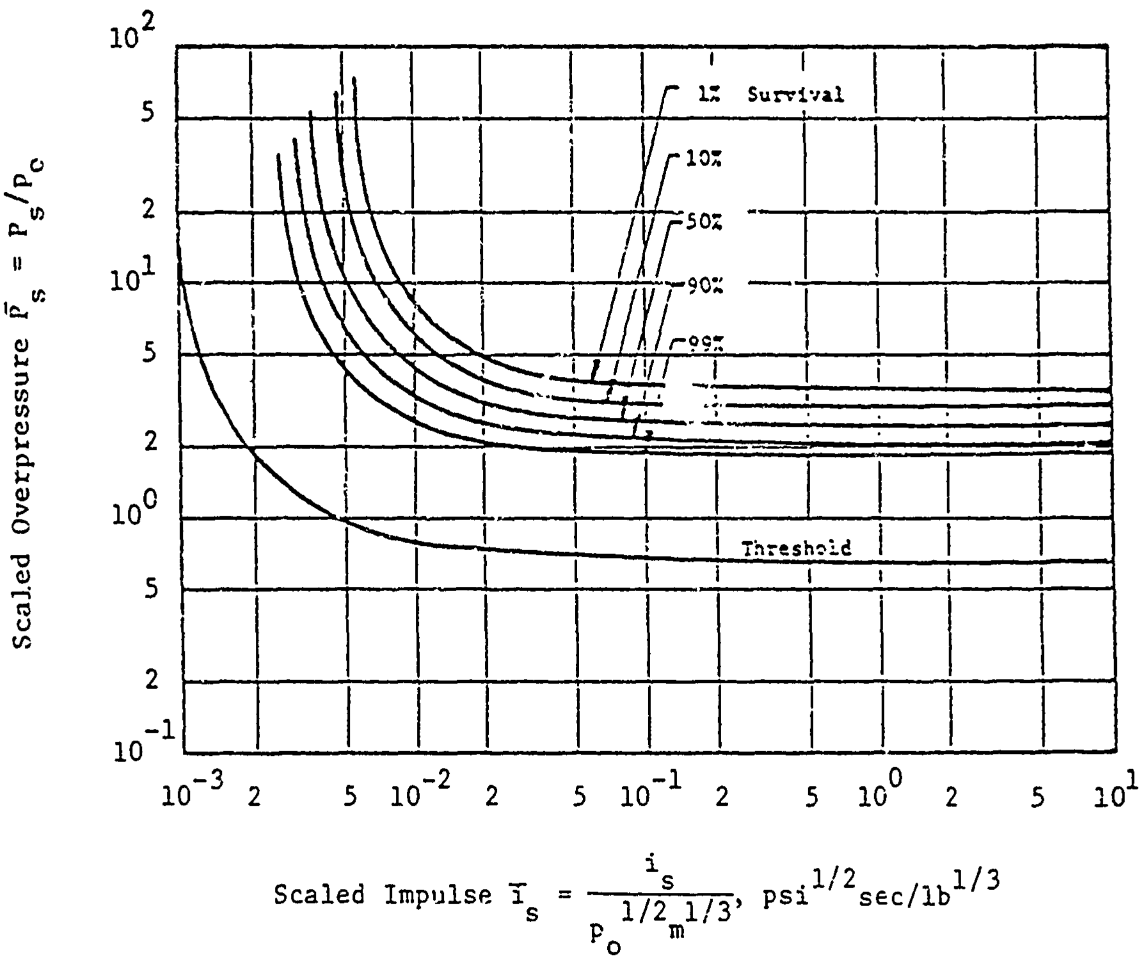


P_s = free field side-on overpressure

i_s = free field side-on specific impulse

TTS = temporary threshold shift

Figure 4-14. Human Ear Damage for Blast Waves Arriving at Normal Angle of Incidence



$\bar{P}_s$ = Ratio of free field side-on overpressure to the ambient pressure (i.e., 14.7 psi at sea level).

$\bar{i}_s$ = Free field side-on specific impulse divided by the square root of the ambient pressure and the cube root of the subject's body weight.

Figure 4-15. Survival Curves for Lung Damage to Man

The free-field, side-on overpressure and specific impulse for a given blast charge and standoff can be obtained from blast curves such as those presented in DOE/TIC 11268 (Ref. 3-15). In performing this exercise it is necessary to double the charge weight shown in Table 4-9. This doubling is necessary to account for blast wave enhancement due to reflection off of the rigid surface.

Performing these calculations for an eight foot thick concrete panel indicates that a 154 pound* man must be at least 55 feet from the charge to be below the lung damage threshold. He would have to be 75 feet away to be below the eardrum rupture damage curve.

Following the detonation of a breaching charge, it will be necessary for the terrorists to cut away rebar to provide an opening large enough for man entry.

Previous testing (Ref. 4-23) indicates that approximately two feet of burning bar is consumed per minute when operating the O_2 supply at 80 psi. Approximately 16 SCFM of O_2 are consumed at this pressure.

A burning bar operated under these conditions can cut through a No. 5 rebar in less then four seconds. The time required to cut other size rebar must be determined or estimated since no experimental data could be located. It should also be noted that terrorists could simultaneously use two or more bars.

Table 4-10 shows the time to cut different size rebars. These times were calculated by comparing the area of a No. 5 rebar to the area of the bars shown in Table 4-10. This ratio was then multiplied by the experimentally determined time to cut No. 5 rebar to provide an estimate of the time required to cut the rebar being considered.

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*Based on DOE/TIC 11268 (Ref. 3-15) recommendation.

Table 4-10. Time to Cut Rebar

Rebar No.	Diameter (in.)	Area (in.^{2})	$\frac{\text{Area (No. i)}}{\text{Area (No. 5)}}$	Time* to Cut (sec)
4	0.5	0.2	0.64	2.6
5	0.625	0.31	1.0	4.0
6	0.75	0.44	1.4	5.8
7	0.875	0.6	2.0	7.8
8	1.000	0.79	2.6	10.0
9	1.128	1.0	3.2	13.0
10	1.270	1.27	4.0	16.0
11	1.410	1.56	4.8	19.0

* This time is calculated based on the results of tests to cut No. 5 rebar using a burning bar (Ref. 4-23).

In performing time-line analyses on specific designs, several assumptions were made. First, in cases where two reinforced concrete slabs are separated by earth, the earth is considered to act as concrete in resisting a breaching charge. However, the charge weight indicated in Table 4-9 was increased by approximately 30 percent to account for impedance mismatches between the concrete and earth. For example, consider a roof consisting of a two foot reinforced concrete slab separated from a four foot reinforced slab by two feet of earth. Assuming this is equivalent to a single eight foot slab, Table 4-9 indicates that 770 pounds of TNT is required to breach the slab. Increasing this by 30 percent yields a charge weight of 1000 pounds of TNT.

Unfortunately, experimental data to determine the effect of earth between the slabs are not available. Therefore, increasing the charge weight by 30 percent represents a subjective estimation of the effect of earth. This is considered to be a conservative treatment of the problem.

The second assumption involves two reinforced concrete slabs separated by air. In this case, SwRI has assumed that the first slab represents a perfect reflector of the air shock. Pursuing this logic, time-line analyses were conducted based on breaching the first slab, and cutting rebar and removing debris to obtain access to the second slab. A second breaching charge must then be used to defeat the remaining wall. Again, this is a subjective evaluation due to a lack of data.

The final assumption regards the time required to cut various rebars with a burning bar. As pointed out earlier, these times were extrapolated based on times to cut No. 5 rebar.

Prior to final design of a shelter, tests should be conducted to evaluate the actual quantities of HE and time required to breach any proposed configuration.

The problem of preventing surreptitious entry into a shelter is deciding where do you draw the line regarding the number of people attacking,

the weapons they possess, etc. From the design side, the resulting question "how thick is thick enough?" yields vague answers. For this reason, SwRI concepts were sized based upon the 747 impact, the 500-pound bomb, and the 300,000 pounds of H.E. Identifying scenarios in which terrorists can enter the building in less then 30 minutes then provides a basis upon which decisions can be made to redesign, throw-out the attack scenario as unreasonable, or change security policies to reduce reaction times. Scenarios which result in penetration in less then 30 minutes are presented in Section 5.5.

Penetrations into the shelter require special attention. Doors, door jambs, and vents may represent the most vulnerable attack points. Therefore, it is important that these locations be designed to resist a terrorist assault for as long as the general structure can resist an attack.

Several options are available to improve resistance time through existing penetrations. At doorways, the resistance time can be improved by designing the door and jamb such that none of the controlling hardware is exposed or accessible from the exterior. The installation and operation would be such that the door could not be forced open using force jacks. A second door can be placed behind the exterior door separated by the wall thickness to force a terrorist group to breach one before the second can be attacked. Door construction can make use of layers or composites. Layers of steel and reinforced concrete can be used to form a stout structure. Door construction can include layers of oak which have been proven successful in defeating burning bars. It may also include spall plates behind any concrete layers to increase the time required to remove debris after detonating a breaching charge. Implementing a spall plate also requires the terrorists to expend more O_2 and burning bar.

Vents should be sized small enough to prevent a person from crawling through to gain access into the shelter. Additionally, the vent pipe should not continue in a straight path from the exterior to the interior. The vent

could penetrate the first concrete slab and then run horizontally for some distance before passing through the second slab to the building interior. In addition, a concrete structure may be built on the roof through which vent pipes pass as illustrated in Figure 4-16. Finally, heavy grates such as nested angles should be in the vent to prevent terrorists from pushing HE down the vent.

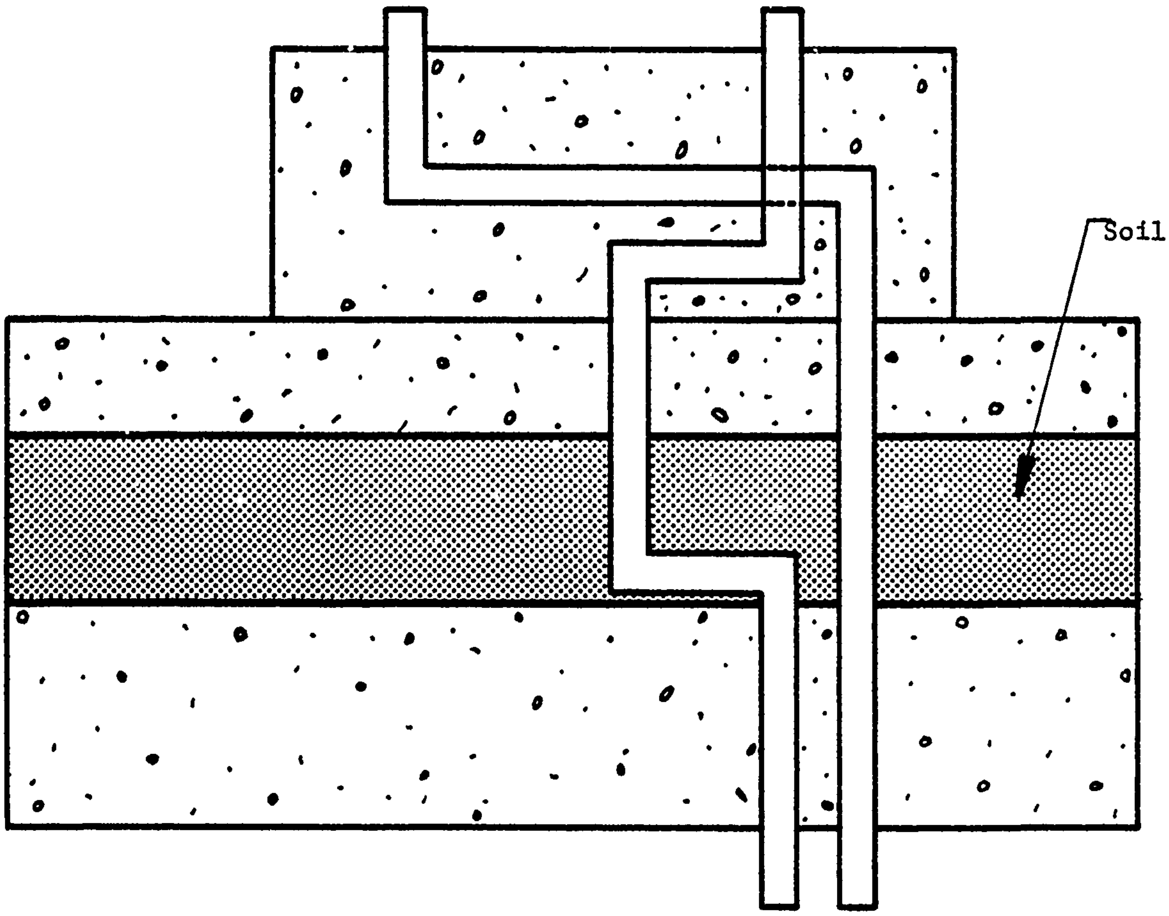


Figure 4-16. Vent Pass Through

4.2 Weapon Handling Processes

The design of the building structure was driven primarily by the survivability considerations described in Section 4.1. The layout of the building, however, was influenced chiefly by workflow requirements. These requirements are explored in the following paragraphs. The weapon handling processes that exerted the most influence on facility layout were (1) weapon movement from a receiving dock to a storage bay, and (2) weapon movement ("loadout") from a storage bay to 5-ton trucks.

Section 4.2.1 itemizes the requirements and constraints applied to the weapon handling functions. Section 4.2.2 discusses some further ground-rules and assumptions established by SwRI during the course of generating the facility layouts. The standard operating procedures developed for moving the weapons are described in Section 4.2.3. A typical time and motion study of the weapon loadout process is illustrated in Section 4.2.4. The necessity to loadout weapons in a chemical warfare environment presents some special problems that are addressed in Section 4.2.5. Section 4.2.6 describes the equipment items needed for weapon handling.

The following discussion is general in the sense that it can be applied to any of the weapon storage facilities under consideration. Implementation in six specific layouts is discussed later in Section 5.4. Calculations supporting the conclusions reached regarding weapon movement and handling are contained in Appendix 8.

4.2.1 Requirements and Constraints

The following performance requirements were established by the Government sponsor at the start of the program:

(1) The equipment selected to move/handle the weapons must be currently approved by the military for handling nuclear weapons, i.e., no new equipment that will require qualification/ certification testing will be considered.

(2) The equipment selected to move/handle the weapons must be compatible with weapon bay sealing requirements for achieving complete explosion containment.

(3) The movement/handling equipment must be able to operate in the debris environment following an explosion in a bay so that undamaged weapons can be removed.

(4) The movement/handling system must minimize manpower requirements.

(5) The movement/handling system must minimize cost (both investment and support).

(6) The movement/handling system must minimize weapon loadout time.

(7) Weapon loadout must be possible in a chemical warfare environment without contaminating the interior of the facility.

(8) There are no time constraints placed on weapon loadout operations in a chemical attack environment.

(9) The facility layout must make it easy to enforce strict control over weapon movements.

(10) Weapons are processed in and out of the facility by serial number.

(11) The movement/handling system must not "do" anything to the weapon or container except move it.

(12) It is to be assumed that standard 2-1/2 and/or 5 ton military trucks will be used to transport the weapons beyond the storage facility.

(13) Only personnel and equipment permanently assigned to the facility will be used for weapon loadout. These assets will not be augmented from external sources.

4.2.2 Assumptions

As the weapon handling concept began to evolve in response to the above requirements, SwRI found it necessary to make some additional assumptions and groundrules to support the concept:

(1) The three workflows that are most important are:

(a) weapon movement from storage to load dock to truck

(b) weapon movement from truck to load dock to storage

(c) weapon movement from storage to maintenance to storage.

(2) The weapon containers are designed with sling points and with provisions for forklift handling.

(3) None of the containers have built-in wheels or are permanently mounted on dollies.

(4) The weapon containers are designed to be picked up from one end by a forklift facing parallel to the long axis of the container.

(5) The weapon containers do not need to be opened during loadout (i.e., serial numbers are readily accessible from the outside of the container).

(6) Electrical power (primary or backup) will always be available.

(7) On-site storage must be provided for equipment used to move the weapons (e.g., forklifts, cranes). On-site storage will not be provided for the trucks used to transport the weapons to and from the facility.

(8) The two-man crew of each truck will be responsible for directing the positioning of the weapons on the truck bed, and for tiedown of the loads. They will not operate the equipment to place the weapons on the trucks.

(9) Truck load capacities for off-road driving conditions will be assumed.

(10) It will be assumed that the trucks are not pulling two-wheeled trailers for added capacity.

(11) The baseline weapons mix at the facility will consist of:

(a) 15 weapons with container size 66 x 14 x 15 inches

(b) 15 weapons with container size 57 x 22 x 21 inches

(c) 15 weapons with container size 168 x 58 x 56 inches

(d) 12 weapons with container size 116 x 37 x 39 inches.

(12) Emergency loadout time for the site is defined as the time to remove all 57 weapons from the facility and load them on 2-1/2 and 5 ton military trucks.

(13) Emergency loadout time does not include the time to tie down the load on the truck bed.

(14) Emergency loadout time is measured under the assumptions that (a) the facility is not under attack by any of the threats outlined in Section 4.1 at the time of loadout, and (b) no internal accidental explosions have occurred at the time of loadout.

(15) No loadout time penalty is applied to munitions in maintenance at the time of an emergency loadout.

The need for and impact of these assumptions will become appa. as the weapon movement and handling operations are explored in the following sections of the report.

4.2.3 Baseline Handling Equipment and Procedures

Current nuclear weapon storage facilities use forklifts and/or overhead cranes to move weapons around. Consequently, the assumption was made that similar equipment would be used for the facilities being designed in this program. Underground sites may utilize platform lifts to reach surface loading docks. Facility layouts that require the development of new, special-purpose handling equipment were discarded from consideration. Electric forklifts are used with all the facility layouts. Bidirectional bridge cranes are also used in some of the layouts depending on the type of weapon storage bay selected. The heaviest weapon in the baseline mix weighs approximately 2900 pounds. The lightest is about 270 pounds. Consequently, mechanical equipment is always required to move the weapons.

The weapons arrive at the storage facility on the beds of 2-1/2 or 5 ton military trucks. The trucks are backed up to a loading dock equipped with dock levelers, and are mechanically fastened to the dock. A forklift from the storage facility drives onto the truck bed to pick up the weapon, and then backs off the bed onto the loading dock. The weapon is logged in by serial number and taken by the forklift to the appropriate storage bay. If a platform lift is used to move between aboveground and underground levels, then the weapon stays mounted on the forklift during the ascent/descent.

When the weapon reaches the storage bay, handling procedures vary depending on the design of the individual storage cubicles in the bay. Several different bay types have been evaluated, and are described in Section 4.5. With some of the cubicle designs, the forklift drives the weapon directly into the cubicle and sets it down. With other designs, the forklift sets the weapon down in the center hallway of the bay and an overhead crane picks it up and deposits it in the cubicle. These details will be discussed for six specific facility layouts in Section 5.4.

When the weapons are removed from the facility, the above sequence of events is essentially reversed. Forklifts or cranes remove the weapons from the cubicle. Forklifts transfer the weapons to the loading dock and drive onto the truck bed to position the weapon. The weapon is logged out by serial number as it exits the building.

Information provided by the contract sponsor indicates that the weapons are designed to be lifted by a forklift facing parallel to the long axis of the munition, as shown in Figure 4-17. This implies that the center of gravity of the weapon is offset from the dimensional center. The assumption regarding the orientation of the container on the forklift is an important one because it influences other decisions regarding door sizes, corridor widths, forklift turning radius requirements, platform lift dimensions, etc. The widest weapon to be considered is 4.2 feet, the longest is 14 feet, and the highest is 4.7 feet.

All of the facility layouts contain four weapon bays, with each bay sized to store 15 of the largest munitions in the baseline weapons mix. Consequently, every weapon size can be stored in any bay. Sufficient forklifts and cranes have been supplied so that all four weapon bays can be unloaded simultaneously. Every layout has two load docks, and each dock can accommodate at least two trucks simultaneously. Each storage bay has convenient access to both load docks.

Figure 4-18 pictures the cargo trucks used to transport the weapons to and from the storage facility. The M813 has a 5-ton payload capacity for off-highway driving. The M35A1 has a 2-1/2-ton payload capacity off the highway. The M813 bed dimensions are approximately 13.8 ft x 8 ft (a long

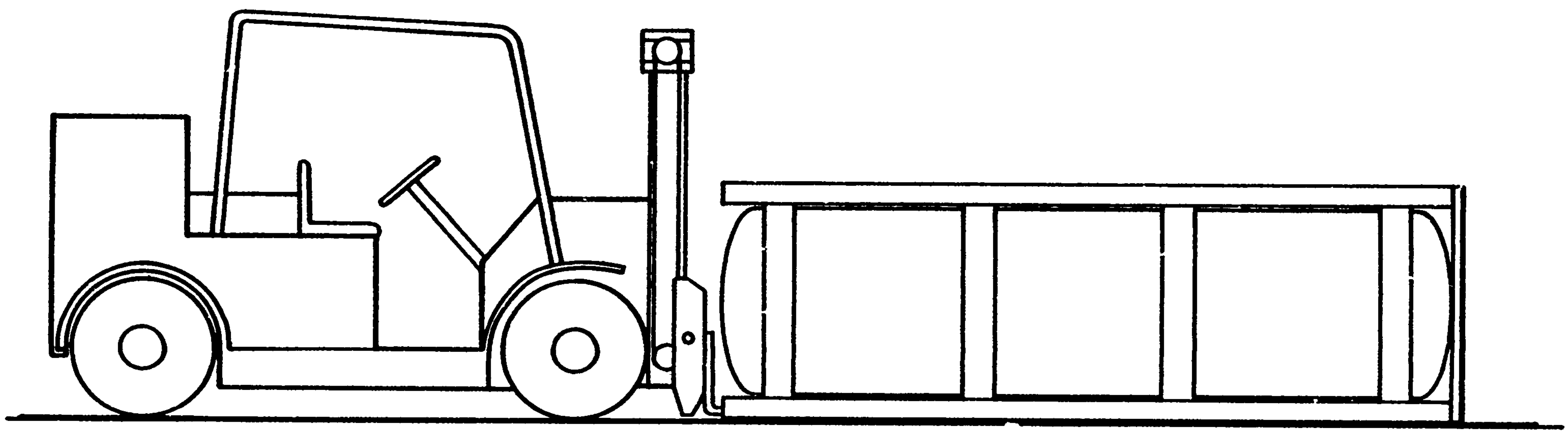
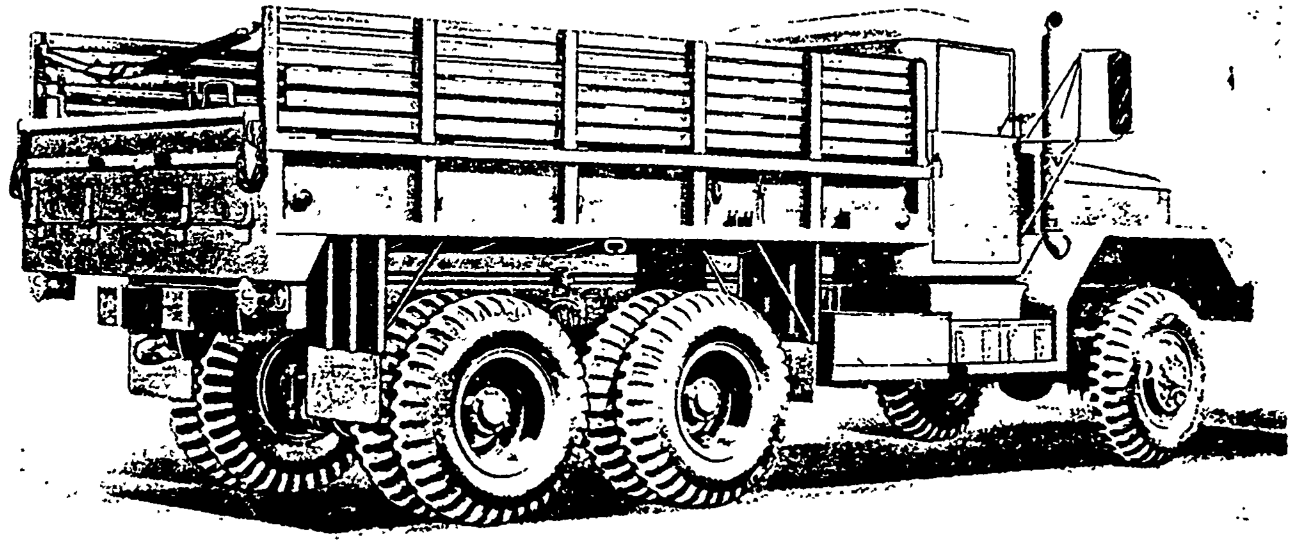
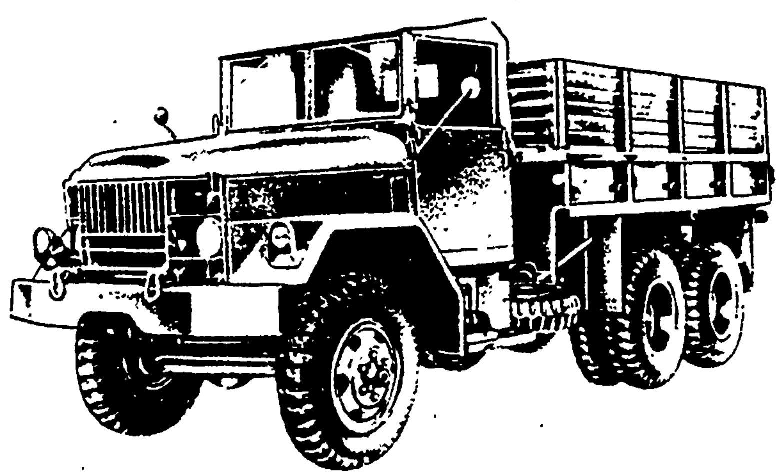


Figure 4-17. Weapon Transport Example



(a) M813 Cargo Truck, 5-Ton



(b) M35A1 Cargo Truck, 2-1/2-Ton

Figure 4-18. Trucks Used For Weapon Loadout

bed version, the M814, is available with a 17 ft x 8 ft bed). Similar dimensions for the M35A1 are 12 ft x 8 ft. The largest weapon in the baseline mix stored at the facility has dimensions of 14 ft x 4.5 ft x 4.5 ft, and weighs about 2900 pounds. Consequently, only one of these can be carried per 5-ton truck. It is assumed that weapons of dissimilar type are not carried on the same truck because they probably have different destinations. Under this assumption, a complete loadout of the 57 weapons in the baseline mix requires either 23 5-ton trucks, or a combination of 16 5-ton trucks + 7 2-1/2-ton trucks.

4.2.4 Generic Timelines for Weapon Loadout

The emergency loadout time attainable with a given facility layout is an important parameter for evaluating and comparing layouts. Consequently, timelines were developed for the loadout process. Recall that emergency loadout time is defined as the time required to remove from the building all 57 weapons in the baseline mix, and place them on 2-1/2 or 5 ton Army cargo trucks. The emergency loadout time is measured under the assumptions that no accidents have occurred and no enemy attack on the facility is underway. Two different types of timelines are needed: one when all weapon handling is by forklift, and the other when both forklifts and cranes are involved in moving weapons. These timelines are discussed in the following Sections 4.2.4.1 and 4.2.4.2, respectively. Application of the timelines to six specific layouts is illustrated later in Section 5.4. Computations are contained in Appendix 8.

4.2.4.1 Forklift Scenario

The sequence of operations for using forklifts to loadout the weapons is shown in Figure 4-19. The sequence on the right side of the figure is for aboveground facilities and the left side is for underground facilities where a platform lift is used to bring the forklift and weapon to the surface loading dock. Table 4-11 illustrates the type of timeline generated for the operations shown on the right side of Figure 4-19. A similar timeline for the left side of Figure 4-19 is included in Appendix 8.

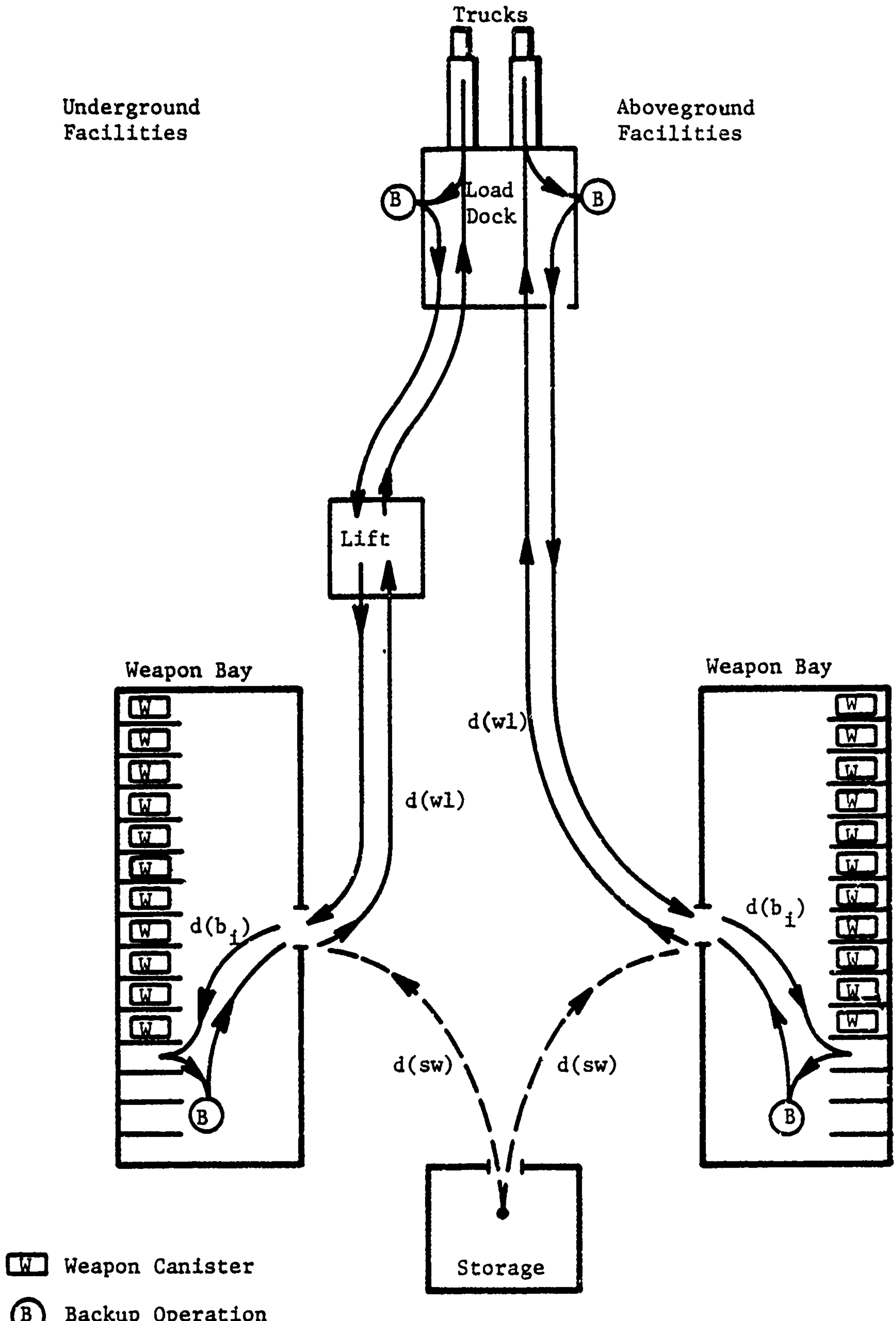


Figure 4-19. Weapon Loadout Procedure Using Forklifts

Table 4-11. Timeline For Loadout With Forklifts - Aboveground Facility

Time (seconds)	Event
300	Loadmaster instructions (in control room)
120	Mount and start forklifts (in storage area)
(120)	Open blast doors on weapons bay
*	Drive from storage to weapons bay - d(sw)
*	Drive from bay door to first cubicle - d(b)
20	Position forklift with tines under canister
75	Tie forklift to canister; raise canister; backup
*	Drive from first cubicle to bay door - $d(b_1)$
*	Drive from weapons bay to loading dock - d(wl)
30	Logout weapon
120	Drive weapon onto truck; position it; set it down; back up
*	Drive from loading dock to weapons bay - d(wl)
*	Drive from bay door to second cubicle - $d(b_2)$
20	Position forklift with tines under canister
75	Tie forklift to canister; raise canister; backup
*	Drive from second cubicle to bay door - $d(b_2)$
*	Drive from weapons bay to loading dock - d(wl)
30	Logout weapon
120	Drive weapon onto truck; position it; set it down; back up
•	Repeat series of steps for cubicles 3 through 15
•	
•	

*Time computed based on distance traveled and assumed forklift rate of travel (loaded = 2 mph; unloaded = 3 mph).

The distances identified in Figure 4-19 must be computed for each different facility layout. The time to travel these distances can then be computed using an assumed rate of travel of 2 mph (3 ft/sec) for a loaded forklift and 3 mph (4.5 ft/sec) for an unloaded one. The platform lift was assumed to travel at a rate of 0.7 mph (1 ft/sec). If the cubicles in a particular bay layout are arranged in such a way that forklift access to one or two cubicles takes some additional maneuvering, then time penalties are added to the basic timeline shown in Table 4-11.

In order to accomplish loadout as quickly as possible, it has been assumed that a forklift will be available for each bay. All four storage bays will be unloaded simultaneously. The number of people required is estimated as follows:

(1) Four forklift drivers (one per storage bay)
(2) Four loading helpers (one per storage bay)
(3) Two clerks for weapon checkout (one per load dock)
(4) One supervisor.

4.2.4.2 Forklift + Crane Scenario

Certain bay layouts under consideration require an overhead crane to take the weapons into and out of individual cubicles. For loadout, the crane places the weapon on the center aisle of the storage bay where it is then accessible to a forklift. The sequence of operations for using the crane is illustrated in Figure 4-20. The forklift part of the operation is almost identical to that already discussed in Figure 4-19. Table 4-12 illustrates the timeline used for crane operations. The forklift sequence of events described previously in Table 4-11 is concurrent with the crane movements. It will be shown in Section 5.4 that the forklift part of the handling takes longest.

The distances identified in Figure 4-20 must be computed for each different facility layout. The time to travel these distances can then be computed using an assumed rate of travel of 1 mph (1.5 ft/sec) for the crane

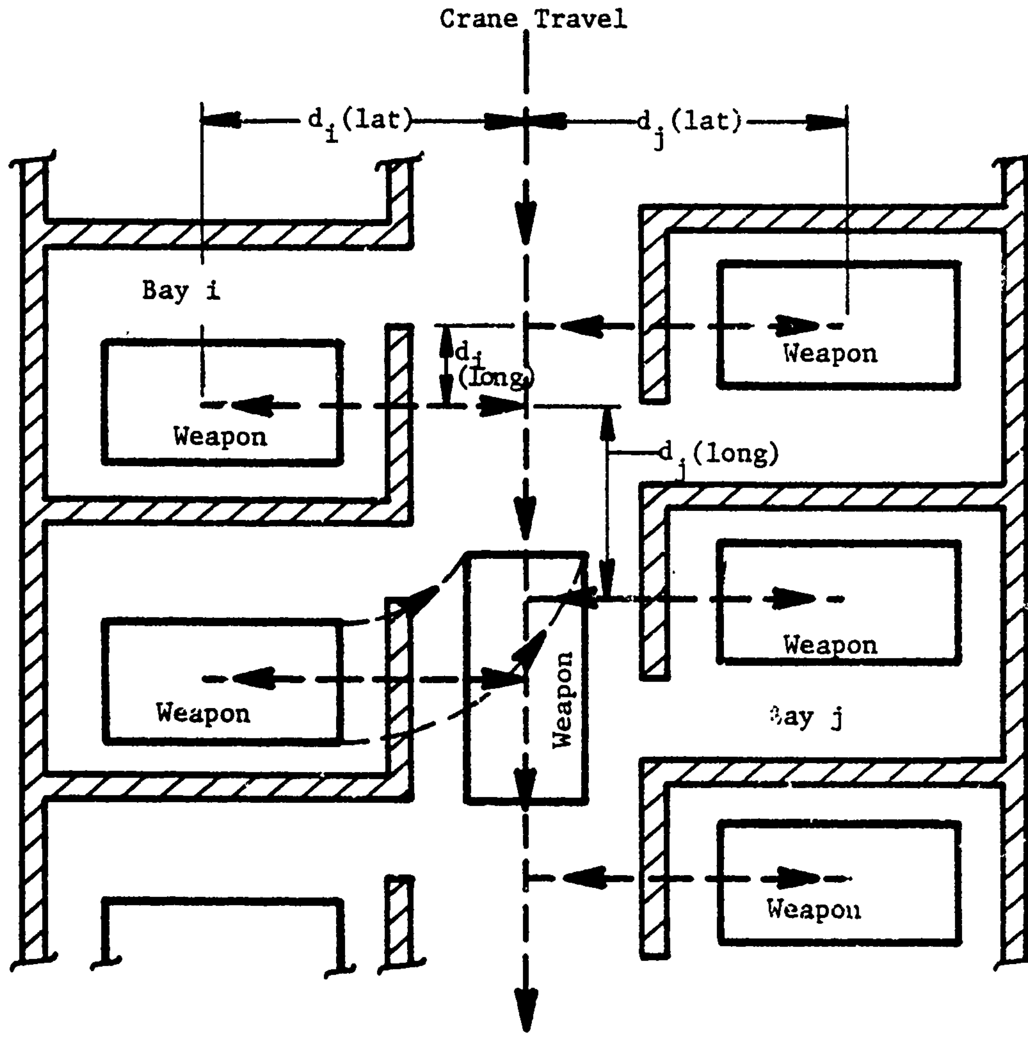


Figure 4-20. Weapon Loadout Procedure Using Cranes

Table 4-12. Timeline for Crane Operations

Time (Seconds)	Event
*	Travel longitudinal distance to cubicle 1 - d_1(long)
*	Travel lateral distance to cubicle 1 - d_1(lat) (The crane is now centered over the weapon cubicle)
30	Fine tune crane position; hook up weapon
25	Lift weapon to 6 foot height
*	Travel lateral distance to center aisle - d_1(lat)
30	Position weapon longitudinally and lower to floor
15	Unhook weapon (The forklift moves the weapon from this point)
*	Repeat series of steps for cubicles 2 through 15.

*Time computed based on distance traveled and assumed crane travel rates:

longitudinal	1.5 ft/sec
lateral	1.5 ft/sec
vertical	0.25 ft/sec

moving laterally or longitudinally, and 0.17 mph (0.25 ft/sec) for the crane moving vertically. These rates were measured on a bridge crane of size similar to the one proposed for the weapon storage facilities.

Certain potential disadvantages must be accepted if a facility layout requiring a bridge crane is selected. First, a mechanical failure in the crane may preclude weapon loadout until the failure is corrected. Unlike a forklift, there is no way to push the disabled crane out of the way and use another overhead crane. This problem may be overcome in some instances if the bay layout gives room to bring in a portable gantry crane in an emergency, or if a forklift is used to lift the weapons with a sling arrangement. A second potential disadvantage to the use of overhead cranes is that structural rotations resulting from an internal explosion or an external blast might jam the crane bridge or cause it to derail and fall.

In order to accomplish loadout as quickly as possible, it has been assumed that a forklift and a crane will be available for each bay. All four storage bays will be unloaded simultaneously. The number of people required is estimated as follows:

(1) Four forklift drivers (one per storage bay)
(2) Four crane operators (one per storage bay)
(3) Two clerks for weapon checkout (one per load dock)
(4) One supervisor.

4.2.5 Chemical Threat Considerations

It is required that the storage facilities be designed to allow for loadout of weapons when the outside atmosphere is contaminated with chemical warfare agents. Furthermore, the loadout must be accomplished without contaminating the interior of the facility. There are no time restrictions placed on this type of loadout. No weapons will be accepted into the facility for storage when the outside environment is contaminated. No equipment decontamination provisions are made in the facility designs.

The movement and handling of weapons inside the storage facility is the same regardless of whether the outside environment is contaminated or not. As explained in Section 4.1.4, in a wartime environment the building interior is maintained at a positive pressure with respect to the ambient outside environment. Consequently, the weapons will be uncontaminated, and personnel will not be required to wear chemical defense clothing. Loadout procedures are the same as described in Section 4.2.3 up to the point where the weapons are driven onto the loading dock.

It is assumed that personnel driving the trucks will arrive at the storage facility in chemical defense clothing, and that the trucks are potentially contaminated. The loading dock area will also be contaminated. Figure 4-21 helps to illustrate how the weapons are safely moved from the clean storage facility to the contaminated loading dock. In a peacetime environment, the doors connecting the loading dock to the main corridor of the building may be left open. In wartime, however, when the building is placed under positive pressure, the door between the corridor and vestibule is closed, locked, and sealed. Pressure on the inside of this door is 0.3 inches of water (0.01 psi) higher than on the outside.

The sealed door to the corridor has a much smaller door placed in it near the bottom, referred to as the "weapons door." This door consists of a set of spring-loaded swinging panels. It is sized so that the largest weapon in the facility can pass through with approximately 0.25-inch clearance. During loadout the weapon is pushed on a roller track through the weapons door from the clean area to the contaminated area. The positive pressure differential across the door face keeps contaminants from entering the protected part of the building.

The weapon is picked up in the vestibule by a forklift and transported to the truck. The forklift driver must wear a chemical defense ensemble. The forklift itself will be contaminated and cannot reenter the protected part of the facility. The driver can enter/exit the facility through the don/doff area described in Section 4.1.4.4.

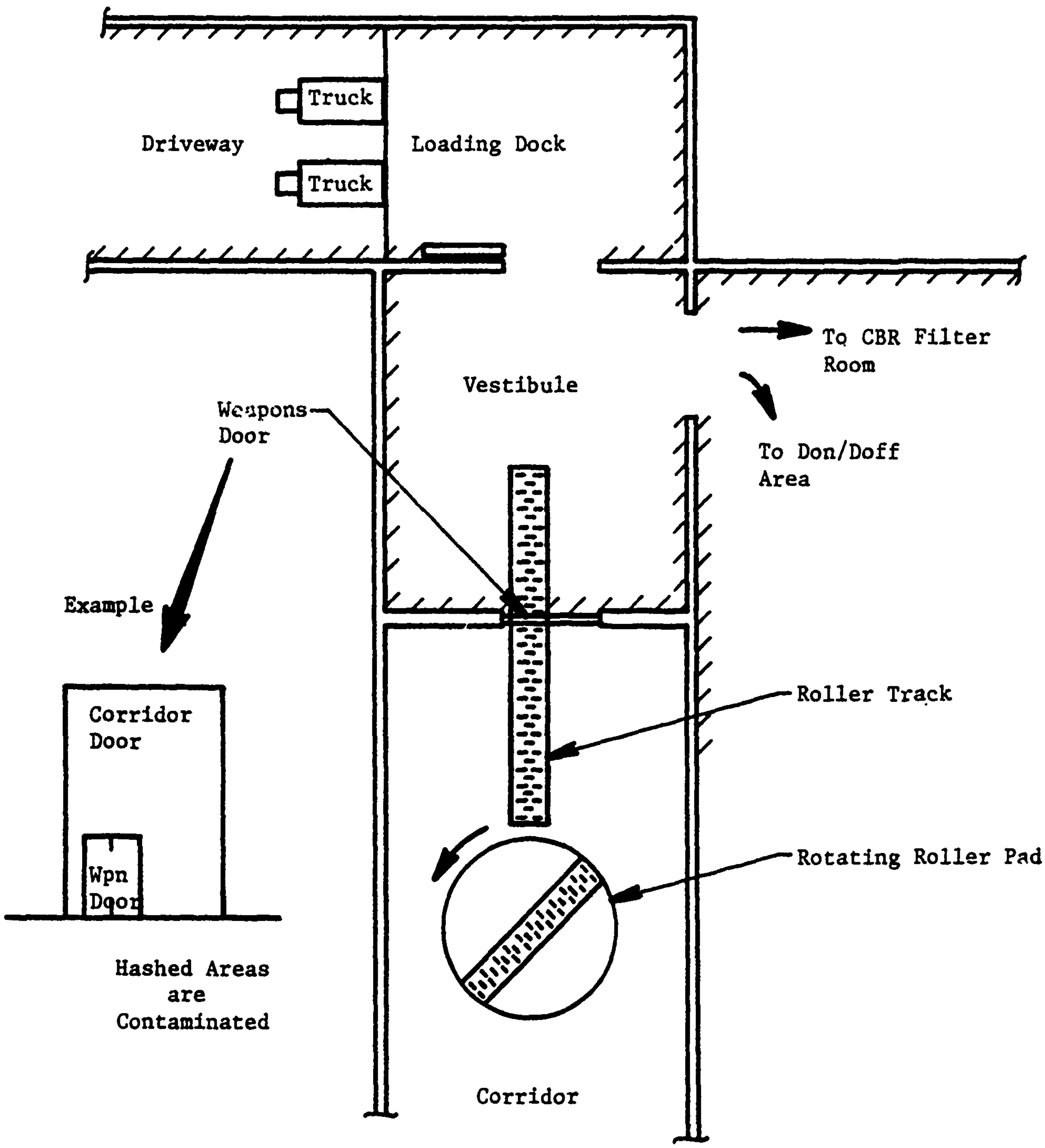


Figure 4-21. Weapon Loadout in a Chemical Environment

Recall that the weapon canisters are designed to be picked up by a forklift from one end only. Consequently, when the forklift brings a weapon from the storage bay to the weapon door, some provision must be made to turn the weapon 180 degrees so that the proper end is facing the forklift that must pick it up outside. This is accomplished with a rotating roller pad as illustrated in Figure 4-21. This rotating pad could have been placed on either side of the weapon door. It was decided to put it on the corridor side of the door for the following reasons:

(1) The clumsiness of working in a chemical defense suit, and the rapid heat stress buildup associated with wearing this suit, make it important that the workload on the person operating the forklift in the contaminated area be minimized.

(2) Placing the rotating pad in the vestibule would result in it becoming contaminated, creating storage and handling problems.

The rotating pad and the roller track extending through the weapon door are standard items in use at commercial warehouses.

When the weapons door is closed and no weapons are being loaded out, air losses through this door will be near zero. Care must be exercised to minimize the air losses when weapons are being pushed through so that the positive pressure of the facility is not lost. The air handling system for the facilities has been preliminarily sized under the assumption that these leaks can be kept to 1000 CFM or less. This appears reasonable, particularly for the large weapons. These will block the doorway nearly as effectively as if the doors were closed. If air leakage during loadout of the small weapons is found to be a problem, it should be feasible to fit the door with a type of flexible or expandable seal that will adapt itself to the shape of the weapons being pushed through the door. Keeping the loss rate to 1000 CFM or below is not expected to be a severe problem, particularly since these losses would occur only when the weapon is being pushed through (less than a minute). They are not constant long term air losses.

Since the weapons door represents an approximately 4.5 foot square opening directly into an area where highly toxic liquids and vapors exist, the concept was carefully scrutinized to ensure its safety. The existence of 0.3 inch of water pressure differential across the door face would certainly seem to preclude the possibility of any backdrafts entering the building carrying entrained chemicals. The only potential hazard that could be identified (and it seems highly unlikely, if not impossible) is the possibility of contaminated air finding a low resistance path into the building through the boundary layer of air along the edge of the door frame since the air right at the boundary layer is probably stagnant or at very low velocity. If this concern is realistic, it can probably be overcome by using some of the traditional boundary layer flow control techniques used by aerodynamacists. Some examples are shown in Figure 4-22. The cut through the corridor door could be given curved edges instead of perpendicular edges to reduce flow separation as the air is channeled through the opening. The corridor door could be made partially hollow with a fan installed to suck air into the hollow chamber from the boundary of the weapons door. Another alternative would be to create a vertical air suction on the contaminated side of the door to give contaminants a vertical velocity component that would prevent their movement laterally along the door boundary layer.

There are two loading docks in every facility layout. Only <u>one</u> will be used for weapons loadout during a chemical attack. Using both docks would have presented the following disadvantages:

(1) The necessity for two weapons doors would significantly compound the demands made on the air pressurization system to overcome air losses during loadout.
(2) Two forklifts would be contaminated and no longer usable inside the facility.
(3) Two forklift drivers would have to work in the chemical environment instead of one.
(4) Two sets of roller tracks and rotating pads would have to be supplied instead of one.

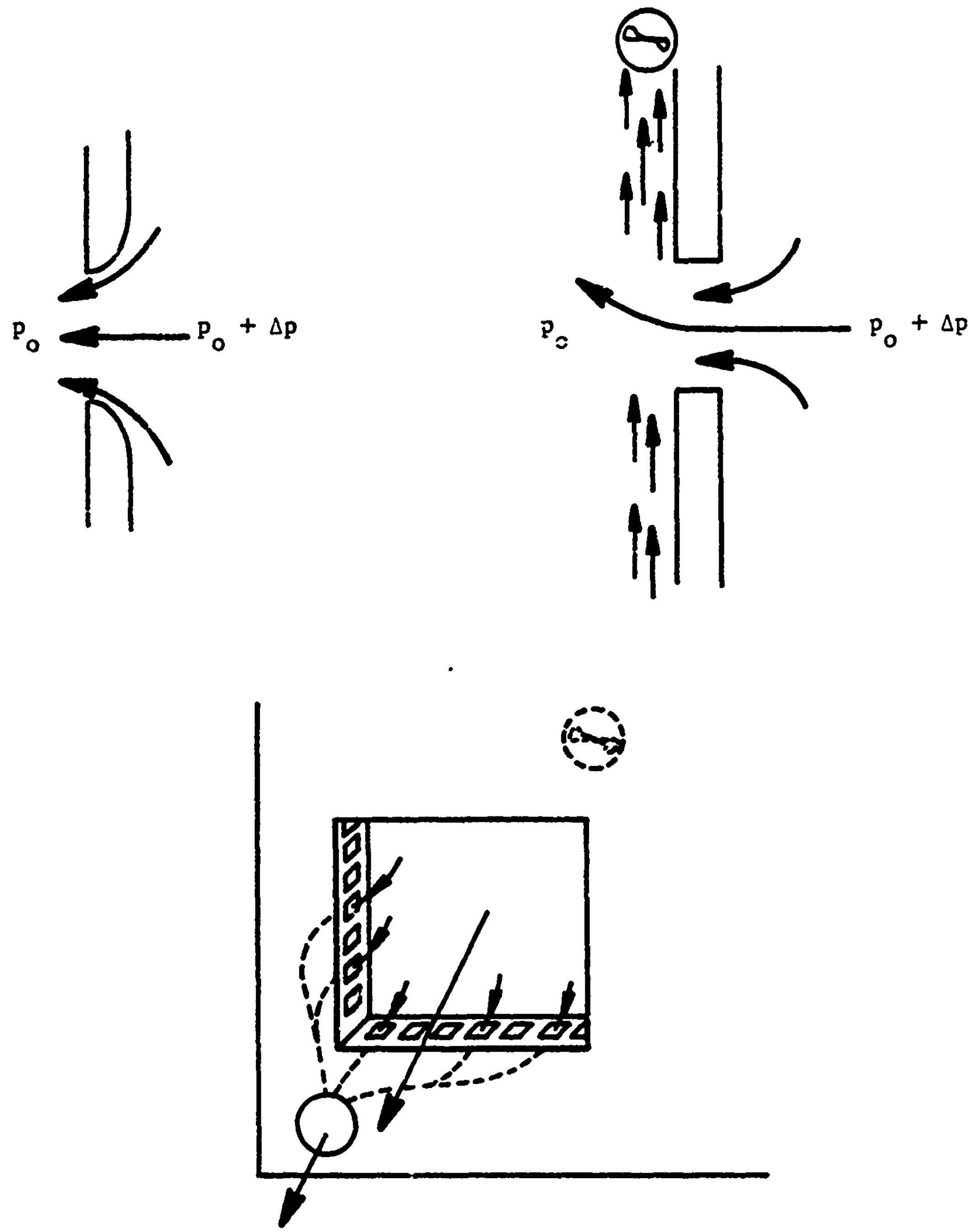


Figure 4-22. Boundary Layer Airflow Control Techniques

(5) Additional corridor space would have to be provided at both load docks to accommodate the rotating pad and roller tracks.

The only advantage of equipping both docks for loadout under chemical attack would be to shorten loadout time. Since no time constraints were placed on this operation, the disadvantages outweighed the advantages, and it was decided that only one loading dock would be used.

4.3 Safety

Throughout the development of the six weapon storage facility concepts, safety was a prime factor and objective. The AMC Safety Manual, AMCR 385-100 (Ref. 3-2), which contains safety policy considerations for such things as nuclear and conventional weapon handling and maintenance, classification and storage guidelines, dividing wall guidelines, etc., was used for safety guidance. For example, all of the dividing walls used in the various bays are at least three feet from the center of the weapon's explosive charge which concurs with requirement 3-6.c of AMCR 385-100. Exceptions to the safety requirements were taken when safety jeopardized security. The government sponsor took the position that security and operations of the facility took priority and would override safety. The areas of safety requirements affected included those pertaining to number of fire exits, distance to fire exits, and door design. The requirement that exits be equally spaced about the perimeter of the facility with no employee more than 25 feet from the nearest exit (Chapter 5-7 of AMCR 385-100), and the requirement that exit doors open outward and during operating hours not be fastened with locks other than antipanic catches or other quick-release devices (Chapter 5-8 of AMCR 385-100), severely jeopardized security and were therefore not adhered to. The weapon storage bays are required to maintain structural integrity following an accidental detonation of a weapon and prevent any sympathetic detonation. The quantity-distance criteria can therefore be dismissed and weapons bays or other areas can adjoin.

Other safety factors such as laboratory safety, lightning protection, materials handling equipment, etc., were considered using AMCR 385-100 as the principal guideline. Fire protection was considered using the National Fire Protection Agency Codes (Ref. 4-24) ar guidelines.

At some existing munitions manufacturing facilities and explosives handling facilities, commercially available explosion detection systems are installed and operating. The critical sensors in these systems are ultraviolet flash detectors which sense the intense flash from an explosion and either trigger alarms or activate water deluge fire sprinkler systems to reduce fire damage or limit this damage to specific cells or areas in a plant.

These systems could be adapted to any of the storage concepts. There are no known commercially available systems for sensing other effects from an accidental weapon detonation, such as blast overpressure or quasi-static pressure rise, although there is a good technology base for development of such systems.

4.4 Subsurface Problems

4.4.1 General

The substructure must transfer the building loads to the ground without excessive settlements or subgrade failure. The prescribed subsurface conditions (Houston-Galveston) require that certain precautions be taken for a high ground-water table and generally poor soil conditions. Design and construction of structures above and below the existing ground level in areas of a high water table are not uncommon practices. There are various techniques applied to such design problems which have been used successfully in the past. The final foundation design is usually based on the results of a detailed geotechnical evaluation of the proposed construction site.

The primary areas of concern for the given subsurface conditions are:

- settlement
- bearing pressure
- hydrostatic pressure
- construction.

The settlement is largely due to consolidation of underlying layers of soft clay deposits. A most straightforward method for minimizing expected settlement is through the use of a "floating" foundation concept. This is a foundation in which the weight of the building is equal to the weight of the excavated soil. The resulting bearing pressure below the foundation is equal to the existing overburden pressure. This concept is today a widely established practice and, in fact, there are examples of its use in the literature dating back to the early 1900's (Ref. 4-25).

The bearing capacity of the existing soil must be adequate to withstand the expected building loads to prevent shearing failure. If the ultimate bearing capacity of the soil is not significantly greater than the expected pressure, one must either reduce the applied loads through foundation structure redesign or modify the soil. An increased bearing capacity can be realized by burying the foundation at some depth below the ground level. If this is not adequate or feasible, various approaches can be taken. Piles or belled piers may be

used to transfer the loads to a depth of reasonable bearing capacity. A mat larger than the building area will help to distribute the bearing pressure to possibly acceptable levels.

In addition to structural modification there are many methods of soil stabilization which are used to increase the bearing capacity of soil masses as well as to eliminate such undesirable behavior as excessive shrink, swell and settlement. This soil stabilization may be in the form of chemical injections. In some instances, cement grouting has been used to create a watertight area for excavation (Ref 4-25). Surcharging a construction area for a certain amount of time with a layer of soil can speed up the consolidation process of a clay layer, thereby reducing the expected settlement during the life of the structure (Figure 4-23). Sand drains can be used to quicken this pre-consolidation process. Finally, simply excavating a certain depth of poor soil and replacing it with compacted engineering fill can reduce settlement and increase bearing capacity.

Hydrostatic pressures can be very critical in the design of structures buried a significant depth below the ground-water table. This must be considered in various ways. Overall hydrostatic uplift can occur if the resultant buoyancy force is greater than the weight of the structure. For the massive concrete structures used in munitions storage, this is generally not a problem. Of primary importance is the ability of the slab to resist the bending stresses caused by the uplift hydrostatic pressure between long unsupported spans. For this reason the slab buried in a high water table area is typically thick and doubly reinforced.

An example of a long span buried slab can be found in the recently constructed Moscone Convention Center in downtown San Francisco (Ref 4-26). The structure is an arch with a 275 ft.-span. A 2-meter-thick mat foundation was designed to withstand the ground-water pressure and house the arch tie-cables. In addition, the cables were placed convex upward for the mat to exert even greater downward forces to resist the hydrostatic uplift pressure.

When construction requires excavation below the ground-water table, in general, dewatering procedures will be required to keep the construction area dry. Typical dewatering methods for both shallow and deep excavation depths

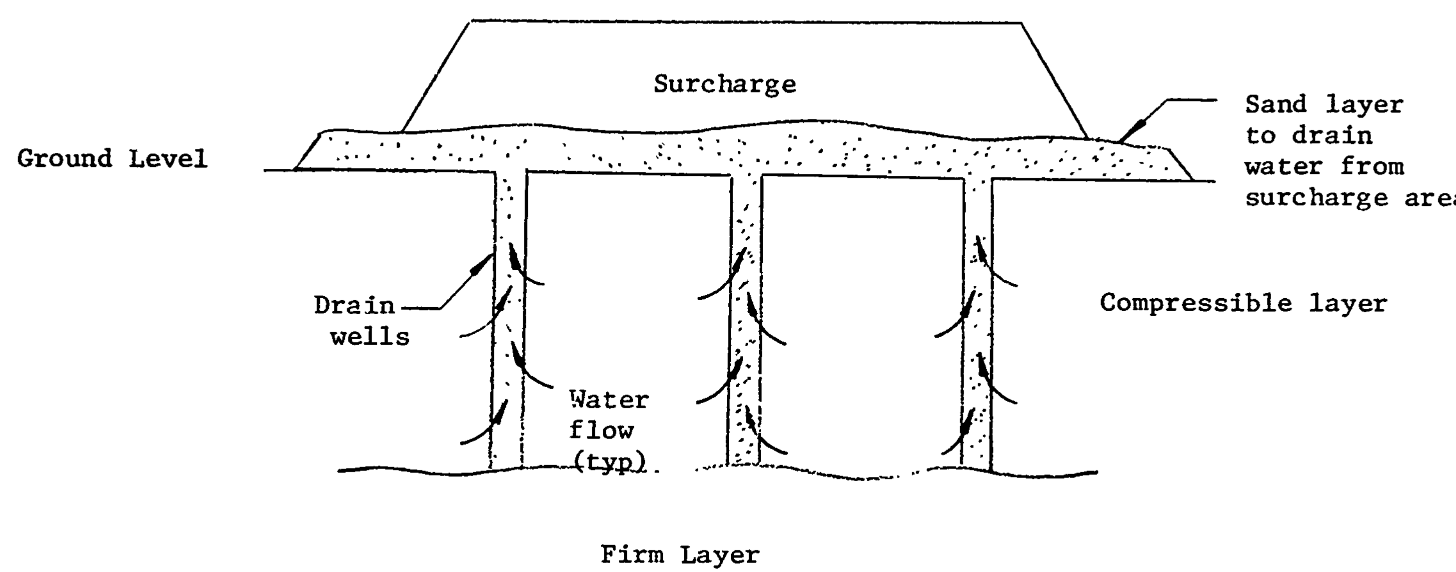


Figure 4-23. Concept for Surcharging Soil Using Sand Drain Installation

are shown in Figure 4-24 (Ref. 4-27). Specific dewatering techniques to be used are determined by actual soil properties and depth of excavation below the water table.

In summary, although high water table and poor subsurface conditions pose certain problems in the sub-structure design, existing technology can overcome these problems. A detailed geotechnical survey is required and then well-established principles of structural and soil mechanics can be applied to design and construct a functional structure.

4.4.2 Soil Conditions

The soil conditions considered were those most generally found in the Houston-Galveston area. Figure 4-25 shows geologic deposits found in the United States (Ref. 4-28). Two basic types of soils can categorize the Houston-Galveston area (Ref. 4-29):

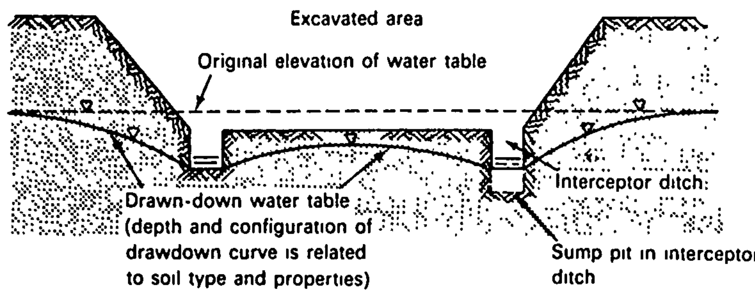
(1) Dominantly clay and mud
(2) Dominantly clay, sand, and silt.

In general, along the coast area, layers of clay are separated by sand and silt deposits. Closer to Houston, clay and mud dominates the subgrade. Table 4-13 summarizes the physical characteristics of these two soil types.

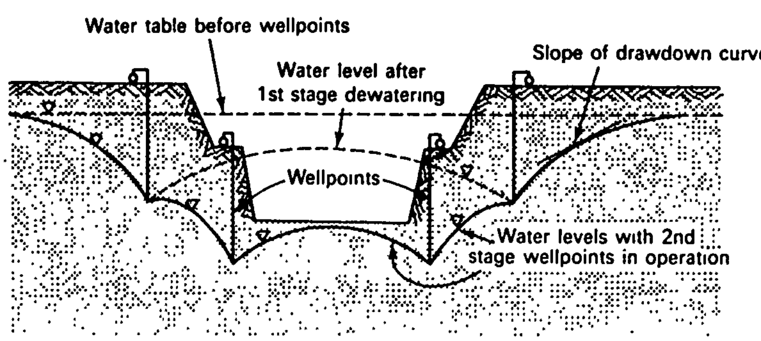
Two additional conditions that greatly affect substructure design are the ground-water level and depth to bedrock. A high water table exists in this area and the bedrock is too deep to be considered as a possibility for any structural load transfer.

4.4.3 Design Approach

Three basic structural concepts were used for purposes of the formation of the foundation design concepts. The first type examined was an aboveground configuration, followed by a partially buried two-level structure, and finally a fully buried configuration.



a. Interceptor Ditches and Sump Pit



b. Wellpoint Operation

Figure 4-24. Concepts for Drawdown of Water During Excavation

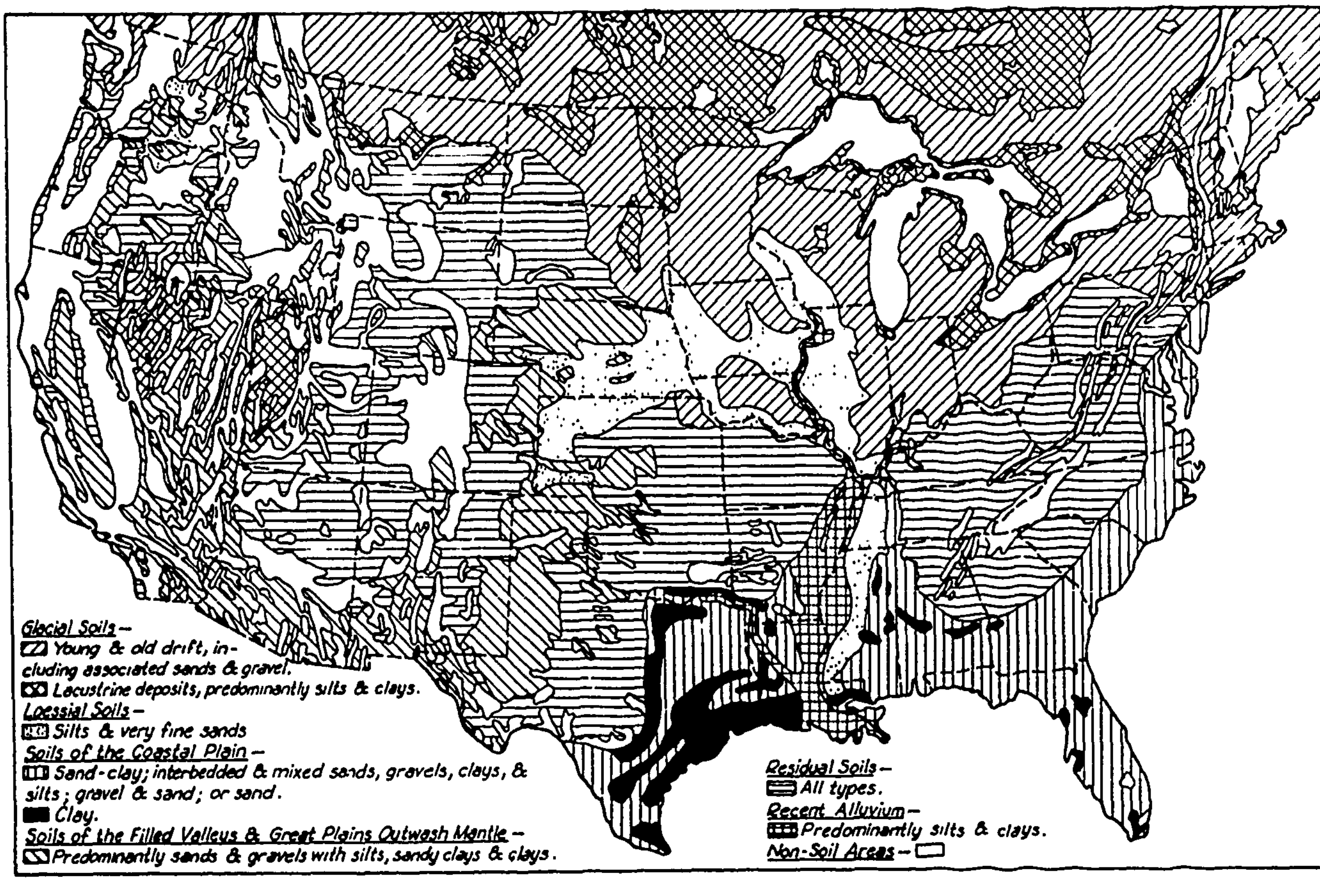


Figure 4-25. Typical United States Soil Deposits

Table 4-13.

Predominant Soil Types in Houston-Galveston Area

(I) Dominantly Clay and Mud
• Low permeability • High water retaining capability • High compressibility • High to very high shrink-swell potential • Poor drainage • Low shear strength • High plasticity
(II) Dominantly Clay, Sand, and Silt
• Moderate permeability and drainage • Moderate water holding capacity • Low to moderate compressibility • Shrink-swell potential • High shear strength

4.5 Bay Selection

This section of the report describes the various types of bay layouts and dividing walls that were evaluated for application to this program. The various requirements, constraints and assumptions that were considered are also discussed.

4.5.1 Bay Design

Four bay designs or layouts were developed for use in this program. Each of the bay designs meets the following requirements:

- Weapons will be stored such that given an accident, there will be no sympathetic detonations.
- Given an accidental detonation of a weapon, storage bays will maintain their structural integrity.
- Weapons will be brought in or removed using conventional material handling equipment, i.e., forklifts, cranes, etc.
- A maximum of 15 weapons will be stored in a bay.
- Bay design must be flexible to allow the storage of either short or long weapons.

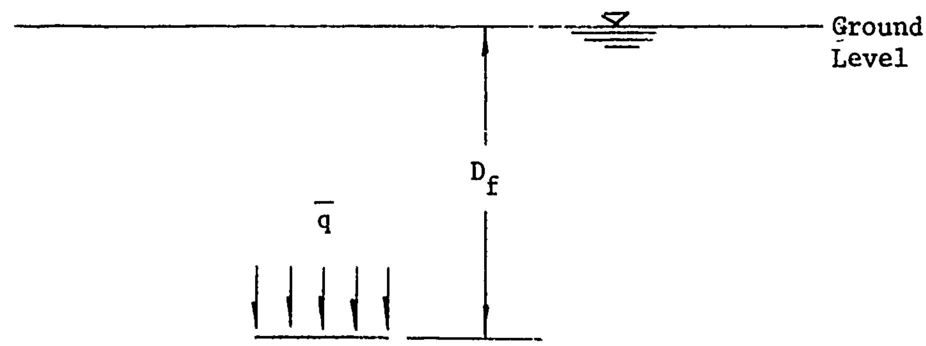
4.5.1.1 Long Bay Design

The first bay design is a long bay, 120 feet long by 40 feet wide. Weapons are stored in a single row of 15 individual compartments or slots, each separated by a dividing wall as shown in Figure 4-28. Each of the weapon storage compartments is 14 feet long and will therefore accommodate either the long or short weapon. The weapons are brought into the bay using a standard forklift with the weapon being carried end-on on the forklift tines. Since the standard forklift has a turning radius of approximately 6 feet, the clear space between the end of the dividing wall and the opposite wall of the bay, 26 feet, is sufficient for the forklift to negotiate any possible turns or maneuvers necessary for depositing or removing the weapon from the storage compartment.

For all three of the above-mentioned cases, the mat foundation was considered as the prime candidate to support the structure due to the soil conditions and the loads incurred on the soil. Depending on the loading conditions, depth of burial, and the type of soil, piles may be required to supplement the mat.

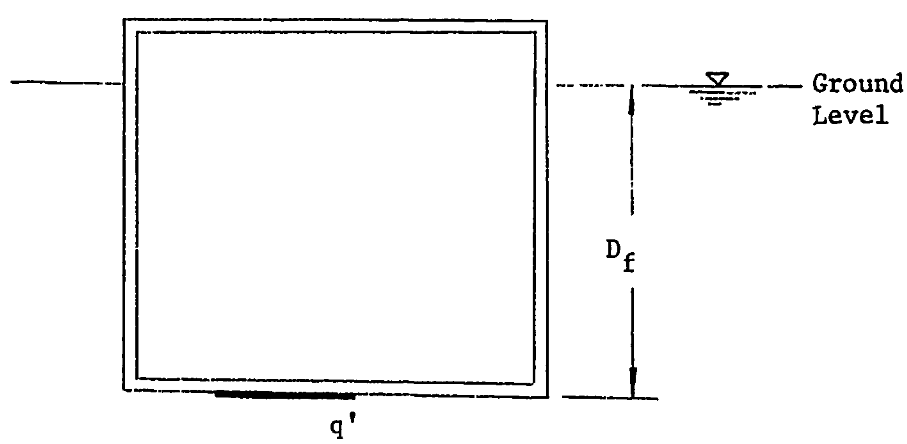
A general approach was followed in the design and analysis of each foundation concept and calculations were based on commonly known theories of soil mechanics and the ultimate strength method for concrete design and analysis (Refs. 4-25, 4-27, 4-30, 4-31). The format involved an initial calculation of the deadweight of the building, including wall, mat, ceiling, and roof loads. This was followed by a check for weight compensation where the weight of the soil excavated equals the weight of the structure replacing the soil. When this condition is met, the soil sees no increase in load, settlement is minimized, and the foundation and structure are considered to be floating. A depth was derived at which weight compensation could be achieved if the present depth was not adequate. Obviously, the floating concept is highly desirable since a multitude of potential problems resulting from settlement could be eliminated. Figure 4-26 shows the concept.

The effective pressure caused by the weight of the building (q') was checked against the allowable bearing capacity of the soil (q_{allow}). The depth of burial was considered satisfactory when $q_{allow} > q'$. However, when $q_{allow} < q'$, the depth required to achieve $q_{allow} = q'$ was calculated. In those cases where the required depth of burial to achieve this condition was not feasible, modification of the foundation and the addition of piles were considered. Once a suitable foundation had been established such that $q_{allow} > q'$, the design was checked against pushout by hydrostatic forces (Fig. 4-27). The design was considered satisfactory if the weight of the building exceeded the buoyant force of the water acting upward on the foundation. As a check to see if the assumed thickness of the slab was adequate, a long span of the mat was checked to determine its capability to withstand the bending moment induced by the hydrostatic uplift. This check should also be done for wall loads. Finally, settlement was determined for those foundations that were not weight compensated. Settlement is highly dependent on the soil conditions, type, and strata which are determined by geotechnical investigation.



$\overline{q}$ = overburden pressure caused by weight of soil prior to excavation

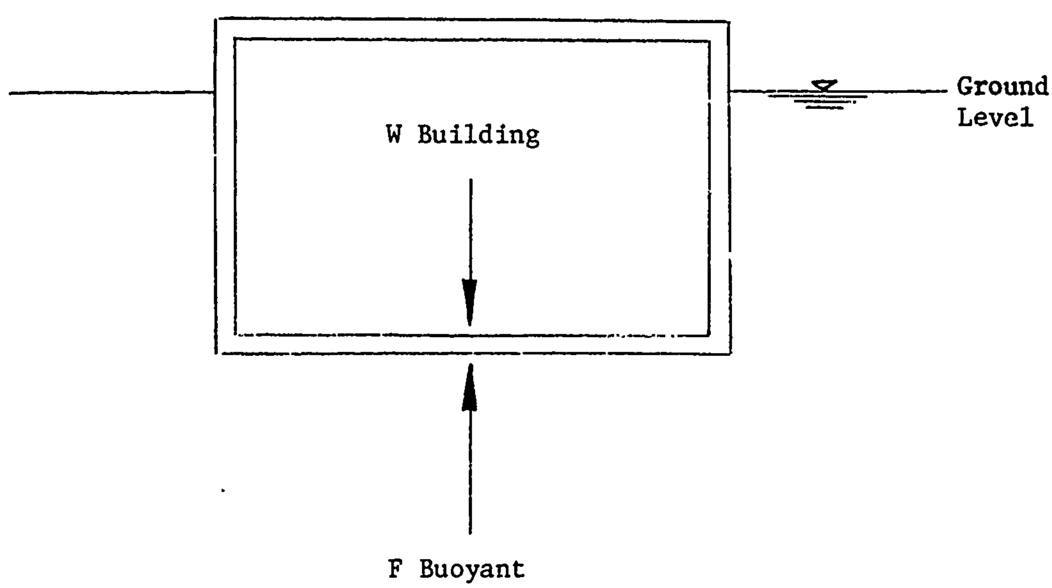
a. Existing Overburden Pressure



q' = effective pressure of building caused by weight of building

b. Effective Pressure of Building

Figure 4-26. Concept of Weight Compensation ($q' = \overline{q}$)



Weight of Building < Buoyant Force of Water

Figure 4-27. Concept of Hydrostatic Uplift

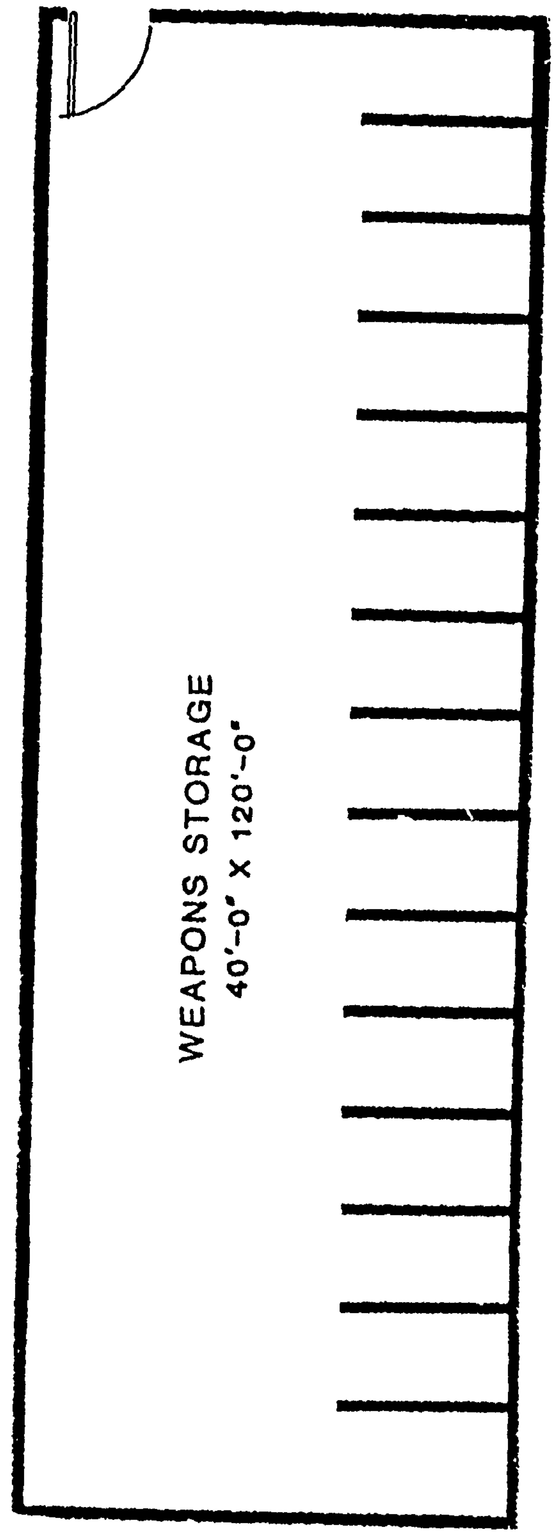


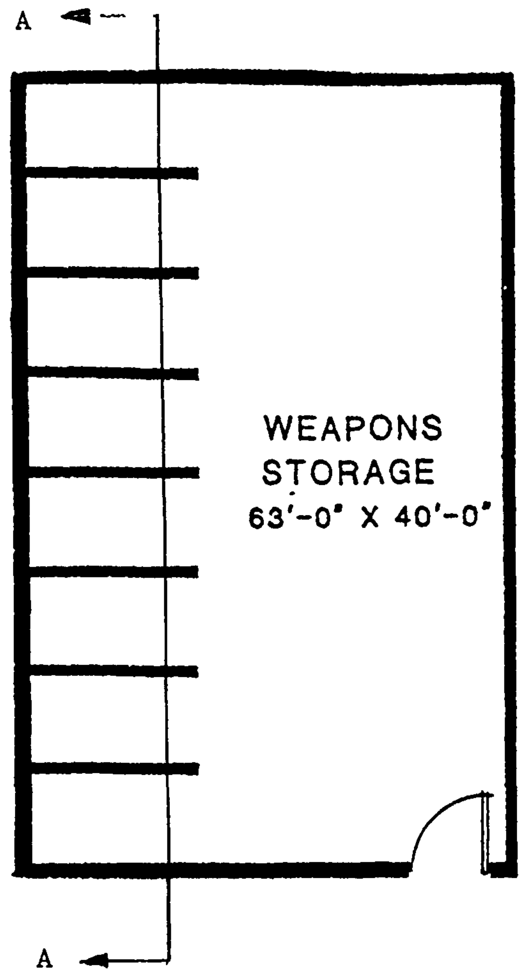
Figure 4-28. Long Bay Layout

4.5.1.2 Stacked Bay Design

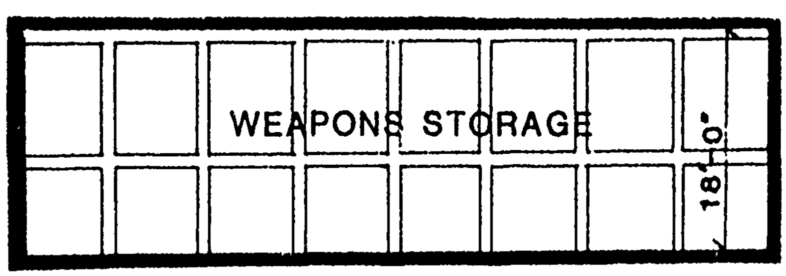
The stacked bay is 63 feet long by 40 feet wide and is very similar to the long bay in operation. Weapons are stored in individual compartments, each separated by dividing walls; however, instead of a single row of compartments as used in the long bay, two rows of eight compartments are used with one row stacked over the other as shown in Figure 4-29. Once again, the compartments are 14 feet long, allowing for storage of either long or short weapons. The weapons are brought into the bay by standard forklift with the longer weapons being carried end-on and the smaller weapons being carried either end-on or side-on depending on the location of their lift hardware. As was the case for the long bays, an access corridor 26 feet wide is provided to allow a forklift carrying a large weapon sufficient turning area.

4.5.1.3 Maze Bay Design

The maze bay design is a bay 71 feet wide by 46 feet long as shown in Figure 4-30. Weapons are stored in two rows of eight compartments separated by a 10 foot access corridor. The weapon storage compartments are protected by 5 foot high "L"-shaped dividing walls. Weapons are brought into the bay by standard forklifts and then an overhead crane is used to lift the munition and position it behind the "L"-shaped dividing walls. Weapons are removed using a crane to lift the weapon out of the enclosure and position it on the access corridor. Forklifts are then used to carry the weapon out of the bay. An entrance has been provided into each compartment to allow personnel access to the munition for positioning or removing the lifting hardware. The entrances are staggered in order to prevent a fragment path from one bay to another, as shown in Figure 4-30. Each weapon storage compartment is 17 feet long and 8 feet wide, thereby providing flexibility in storage of different weapons. Since only 15 compartments will be housing weapons, the remaining compartment can be used as an equipment storage compartment.



a. Floor Plan



b. Wall Section A-A

Figure 4-29. Stacked Bay Layout

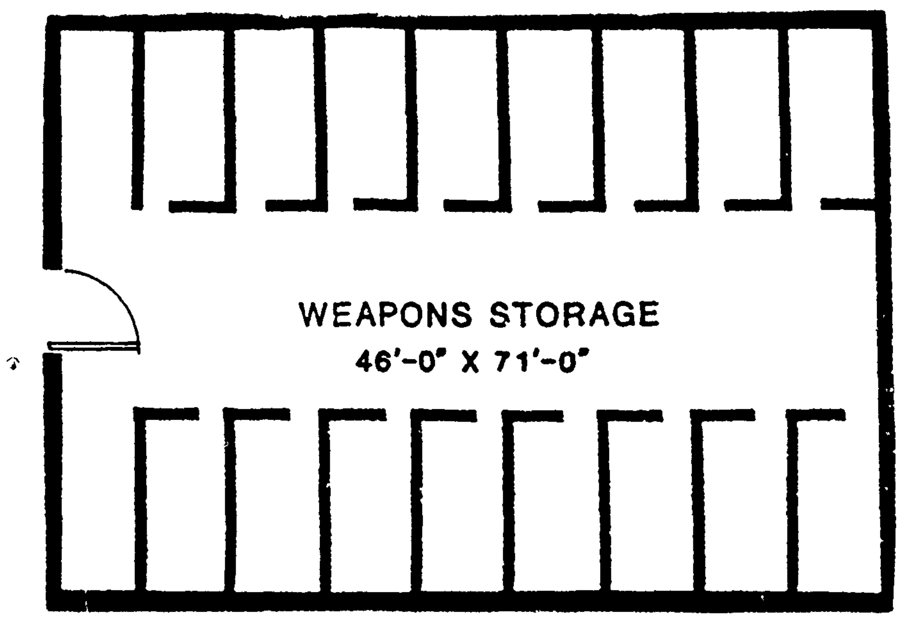


Figure 4-30. Maze Layout

4.5.1.4 Pit Bay Design

The pit bay design is a bay which is 71 feet long and 44 feet wide as shown in Figure 4-31. The weapons are stored in two rows of below-floor-level compartments or pits with the rows separated by an access corridor. Each pit is 17 feet long, 8 feet wide, and 5 feet deep, providing for flexibility in storage of weapons. Weapons are brought into the bay by forklift and then positioned in the pit using an overhead crane system. Weapons are removed by using the overhead crane to lift the weapon out of the pit and position it on the access corridor. A forklift is then used to carry the weapon out of the bay.

4.5.2 Dividing Wall Comparison

The dividing walls between individual weapons in a storage bay must meet two requirements:

1. Lateral deflection under the blast load must be limited so that the wall does not impact the weapon container in the next cell.
2. The wall must stop the "worst case" fragment.

A typical dividing wall was taken to be 5 ft high, 14 ft long, and spaced 7 ft face-to-face from adjacent walls. An 80-lb HE charge is placed on the floor in the center of this 14 ft x 7 ft area. Detonation of this charge produces a triangular pressure-time pulse with a peak pressure of 26,000 psi and a duration of 0.14 msec (see Appendix 7 for details). This pulse represents the initial blast load multiplied by 1.75 to account for reflections off adjacent dividing walls. Quasistatic pressures act on both sides of the wall and thus do not contribute to the loading. A threat was selected which could be analyzed to determine a worst-case fragment to use in designing a bay for total containment. A 0.4-lb steel cube was selected as representative with a velocity of 3000 ft/sec. Using this impact velocity into a barrier of steel, sand, concrete, or a combination of any of these, penetration was calculated. Penetration of the steel fragment into steel was determined using the THOR equation, Ref. 4-32, for the ballistic

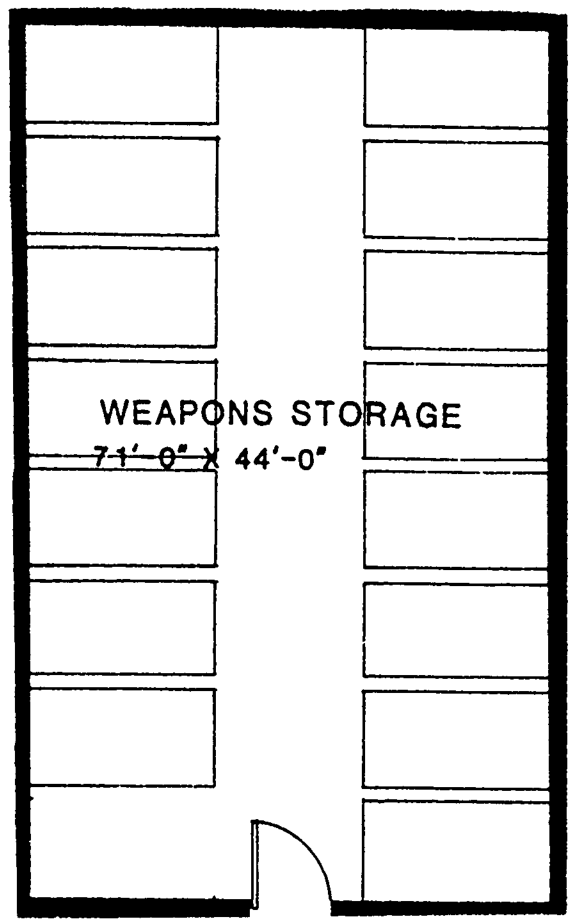


Figure 4-31. Pit Bay Layout

protection velocity. To calculate the depth of penetration into concrete, a modified NDRC equation, Ref. 4-33, for depth of penetration was used. Using another NDRC equation (also from Ref. 4-33), the depth to prevent perforation of the concrete was calculated. Sand penetration was estimated using a prediction curve in the Army Technical Manual TM5-1300 (Ref. 3-11). The worst-case fragment requires 1.6 inches of steel, or 26 inches of sand, or 10 inches of concrete, or a proportional combination of any of these for containment. Detailed calculations of fragment penetration are also included in Appendix 7.

Several different combinations of these materials were investigated for their suitability as dividing walls:

1. Reinforced concrete walls
2. Steel structural shapes (suppressive shields type construction)
3. Steel plates separated by sand or concrete fill
4. Separated steel plates with webs for increased moment resistance.

The steel plates and webs (combination 4) proved to require too much steel and were judged too expensive. The structural steel shapes would easily provide the required moment capacity but the 1.6 inch total thickness requirement for stopping the fragment resulted in excessive weights. The steel plates separated by sand or concrete fill were acceptable and would require a total wall thickness of up to 18 inches. Reinforced concrete walls of 12-inch thickness were found to be satisfactory. These walls were investigated for back-surface spall produced by the fragment impact, and the spall velocities were small enough to not require spall plates.

In summary, both the 12-inch concrete and the sand-filled steel plate walls are acceptable for a 5-ft-high wall. The sandwich wall would not, however, be suitable for the double-stacked storage concepts where the dividing wall must provide structural support for the upper level of weapons. Details of all of the above calculations are presented in Appendix 7.

4.6 Layout Se ection

In this section of the report the weapon storage layouts that were developed are discussed along with the requirements and constraints associated with the layouts, the assumptions made by SwRI, the rating system developed for ranking the layouts, and the final six layouts selected.

4.6.1 Requirements and Constraints

Early in the program, a baseline list of requirements for the weapon storage facility was developed by SwRI under the direction of both CERL and DNA personnel. This list of requirements and constraints includes the following:

- Weapon storage facility should house weapon storage bays, maintenance bay, personnel and equipment support area, control room, and loading docks.
- The maintenance bay will require a 4000-lb overhead crane.
- Work flows to be considered are from storage to the loading dock to the outside and vice versa, and from storage to maintenance back to storage.
- A 12-foot clear ceiling height is to be considered for the maintenance bay.
- Loadout of the weapons should not require access through the maintenance bay.
- Signature minimization is to be provided such that the facility will keep a low-key attitude toward the local populace.
- Only NRC-approved handling equipment will be used.
- The containment design and storage bay size shall be made to accommodate the largest weapon, thereby providing storage flexibility.
- A maximum of 60 weapons will be stored in the facility with no more than 15 weapons per storage bay.
- Facility design should also consider reusability for purposes other than weapons storage.

- The facility shall be designed for operation with a minimum requirement for personnel.
- Operational efficiency, particularly during loadout, is essential.
- The facility shall be designed to withstand a chemical attack and still be able to load out weapons.
- Total containment of an explosion within the bay of occurrence for both weapons and maintenance bays.
- Survivability and security from the various exterior threats described in Section 4.1, including aircraft impact and terrorist attack.

The numerous constraints described above guided the floor plan development. Some constraints required the floor plan to take on a certain shape; other constraints led to preferred, but not required floor plans; still other constraints led to conflicting preferences in the layouts.

The requirement for facility protection during a chemical attack leads to a preferred storage complex as a single building with adjoining bays in a compact arrangement. This layout would include a common corridor connecting all weapons, maintenance, support, and control areas. Operations could continue while this enclosed, compact building was protected from the chemical environment. If a spread out complex is deemed necessary, then connecting, enclosed corridors are required. A spread out enclosure such as this would induce difficult HVAC and air ducting problems. This might require individual HVAC systems at each separate area of the complex. The complex layout that would prove unacceptable under a chemical environment is one that is spread out and unconnected. This would require that all personnel involved in operations be fully suited in chemical protection gear for long periods of time. This gear is clumsy, heavy, and uncomfortable. The fewer facility personnel required to suit up the better. One can imagine a complex with separate weapon bays connected by a road or path to a centralized maintenance and support area. Under a chemical attack, personnel could be caught outside and exposed. Other personnel inside one area would have to remain in place for the duration if suits were unavailable at that area. Any movements of weapons would require protection gear for all

operators. A compact, single building is by far the preferred choice when considering the chemical threat.

Other external threats are the impact of a 747 aircraft and a 500-lb bomb. If a compact layout was considered with, for instance, adjoining weapons bays, then the damage caused could involve more than one bay. This would make a spread out facility attractive because only one weapons area could be involved in an aircraft or bomb impact. However, a compact floor plan would provide a small and difficult-to-hit target. Damage to adjoining weapons bays by a single hit would be a problem if these exterior threats were considered frequent occurrences. If they are rare events compared to the lifetime of the structure, then adjoining bays would not present a problem. This is particularly true if adequate structural protection is provided.

The terrorist threat must be addressed to prevent intrusion through walls, roofs, and entry ways. A spread out complex poses many problems for security, both in detection and prevention of intrusion. A compact layout would minimize the exterior wall and roof area. A simple shape without "hidden" areas would ease the detection problem. The fewer the entrances the better. The smaller the entrances the better. If the facility could operate with one small entrance, this would be optimum for security. However, a single entrance could be sabotaged or barricaded in a "closed" position. This would mean that, although the inside of the complex is not harmed, the complex is rendered inoperable. Therefore, separate and redundant entrances provide benefits.

When considering operational efficiency, two items are important, operations within the complex and loadout. Operations inside the facility lend themselves to a compact layout. Weapons movement and personnel movement are minimized. However, during loadout, choke points can occur particularly if only one load dock is provided. A complex which is spread out with separated weapons bays can provide for simultaneous ongoing loadouts.

The requirement for total containment in case of an accidental explosion inside a weapons bay precludes any venting to the outside.

Therefore, a bay with an exposed exterior wall which can act as a blow-out panel is not necessary. Total containment precludes any need for interline distances between weapons bays and other weapons bays or areas. Therefore, a compact building is possible with no particular need for the weapons bay to have at least one exterior wall. Of course, a spread out complex is also acceptable when considering an accidental explosion. This would, however, offer no advantages over a compact layout where blast walls could be shared by adjoining bays.

After consideration of the above items, it was determined that a single, compact, and enclosed facility layout was preferred. The facility should have at least two load docks with more as necessary to provide efficient loadout, while minimizing the number for security purposes. Any spread out facility considered must have all areas connected and enclosed; however, these will be given less precedence than the compact layout.

4.6.2 Assumptions

Several key assumptions were made by SwRI pertaining to the areas required for the various bays and pertaining to the operational procedures to be used in the storage facility. The following areas were considered as baseline using the information provided by the government sponsor during the initial project meeting:

- Weapons bay - several types as described in section 4.5 (4 bays),
- Personnel and equipment support bay - 6400 square feet,
- Maintenance bay - 1600 square feet,
- Control room - 500 square feet,
- Loading dock - 500 square feet per dock (2 docks).

The following assumptions pertain to the handling of munitions and the operational procedures:

- Material handling equipment will be limited to forklifts, cranes, conveyors, and lifts,

- Weapons will not be equipped with dollies or wheels,
- The longer weapons are designed to be carried by a forklift end-on. Lift on sling points will also be provided on all weapons.

4.6.3 Design and Evaluation of Preliminary Layouts

With the aforementioned requirements, constraints, and assumptions in mind, a total of 43 preliminary facility layouts were developed and copies of these layouts are included in this report as Appendix 1. Since several of the layouts were similar in design, it was decided to divide the layouts into groups. Within these groups, the layouts vary in shape, i.e., square, rectangular, semi-circular; size; type of weapon storage bay; number of maintenance bays; number of personnel areas, equipment bays, and number of control rooms. An evaluation or ranking scheme was developed to assist in the selection of the optimum layout in each group. This evaluation scheme is further described in the following paragraphs.

4.6.3.1 Evaluation Scheme

The ranking system developed for selecting the optimum design in each group consisted of 11 major categories or areas of importance as shown in Table 4-14. Each category was arbitrarily assigned an importance factor: high, medium, or low, to which a multiplier was assigned, i.e., high-multiplier factor of 3, medium-multiplier factor of 2, low-multiplier factor of 1. Each layout was ranked by categories and was arbitrarily assigned a point value ranging from 10 for the highest rating to 0 for the lowest rating. The criteria involved in awarding points to a layout for each category are described in the following paragraphs.

The point system for category 1, "Total Floor Area" was determined by awarding a point value of 10 to the smallest floor area of the 43 layouts, and a value of 0 to the largest floor area of the 43 layouts. The range of floor areas between the lower and upper limits was incrementally awarded points. The increments are given in Appendix 1. The "Total Floor Area" category was considered a high importance category and was therefore awarded an importance multiplier of 3.

Table 4-14. Ranking of Facility Layouts

Categories

1. Total Floor Area (H)*

2. Operational Efficiency

   a) Bay-Maintenance-Bay (L)*
   b) Loadout (Forklift-10; Crane-7) (H)

3. Expandability (L)

4. Load Dock Separation (>150'-10; Opp. Sides-10, <150'-0) (H)

5. Perimeter Wall Area (M)*

6. Bay Interior Wall Area (M)

7. Squareness of Rooms and Bays (M)

8. Number of Blast Doors (5 Doors-10; 6 Doors-9) (L)

9. Weapon Bay Location (Interior-10; Exterior-8) (L)

10. Number of Maintenance Bays (1 Bay-10; 2 Bays-5) (H)

11. Equipment Needs

   a) Base Needs (2 Forklifts-10; 2 Forklifts Plus 2 Cranes-7) (H)
   b) Redundancy (Forklift-10; Crane-0) (H)
   c) Power Requirements (Forklift-10; Crane-7) (H)

---

*Importance Multiplier

High (H) - 3
Medium (M) - 2
Low (L) - 1

The second category, "Operational Efficiency" was divided into two subcategories: a) Bay to Maintenance to Bay, and b) Loadout. The "Bay to Maintenance to Bay" subcategory was considered a low importance function and was therefore awarded a multiplier of 1. The "Loadout" subcategory was considered high importance and was awarded a multiplier of 3. In the "Loadout" subcategory, if only forklifts were used for the loadout, a point value of 10 was awarded. If a crane was necessary, a lower point value of 7 was awarded because crane breakdown would slow loadout. (If a forklift breaks, it can easily be replaced with another forklift.)

Category 3 was expandability, or how easily can additional weapon storage bays be added to the facility. This category was considered a low-priority item.

"Load Dock Separation," category 4 was considered a high-priority item due to the requirement of being able to load out munitions following an attack. It was decided that at least two load docks would be necessary for loadout and if the docks were separated by at least 150 feet or were on opposite sides of the facility, any one of the possible threats would only destroy one of the docks, leaving the other dock available for loadout. Layouts with docks 150 feet apart or on opposite sides were awarded a value of 10, while layouts with docks less than 150 feet apart were awarded a value of 0.

Category 5, "Perimeter Wall Area" was considered a medium importance item and was given a multiplier value of 2. Layouts were awarded points in a similar manner to category 1 in that the smallest perimeter wall area received a 10 and the largest perimeter wall area received a 0. Perimeter wall areas in between were awarded points in increments as shown in Appendix 1.

Category 6, "Bay Interior Wall Area," was also considered a medium importance item and was treated similarly to categories 1 and 5. Appendix 1 gives the point/area award scheme.

Category 7 dealt with the relative squareness of the various bays and was considered a medium importance item, with a multiplier of 2.

"Number of Blast Doors," category 8, was considered a low importance item. A review of the 43 layouts showed that the fewest number of blast doors in any one layout was five, and the maximum number of blast doors, with only one exception, was six. Therefore, since it was preferred to have the fewest number of blast doors possible, layouts with five blast doors were awarded a point value of 10, and layouts with six blast doors were awarded a point value of 9.

Category 9, "Weapons Bay Location," was considered a low importance item. Bay location was judged as to whether the weapon bay was interior, i.e., the weapons bay was centered inside the facility, surrounded by other bays, or exterior, i.e., the weapon bay walls were the facility perimeter walls. An interior weapons bay condition provided additional security in that terrorists would have to defeat the facility perimeter wall and then defeat the weapons bay wall. Since exterior weapon bay walls were also the facility perimeter walls, terrorists would only have to defeat one wall and they would then have access to the weapons. Layouts with interior walls were awarded a value of 10, and layouts with exterior walls were awarded a value of 8.

Category 10, "Number of Maintenance Bays" was considered a high importance item and layouts with two maintenance bays were penalized due to the necessity for redundant maintenance equipment. Layouts with a single maintenance bay were awarded a point value of 10 and layouts with two bays received a 5.

Category 11, "Equipment Needs" was considered a high priority item and received a multiplier of 3. This category was broken down into three subcategories; a) base needs, b) redundancy, and c) power requirements. If the only equipment needed for any of the three subcategories was a forklift, then the layout received a 10; if cranes or cranes and forklifts were needed, the layout received a lower point value as shown in Table 4-14.

4.6.4 Selection of Optimum Layouts

Each of the 43 layouts was evaluated using the aforementioned criteria. The highest ranking layout from each of the groups was identified and these layouts were further evaluated to select the best six layouts. These six layouts were then evaluated for structural design, threat resistance, etc., to develop the six concepts. In the process of converting these six preliminary layouts to six concepts, the layouts themselves underwent changes and/or modifications. The six layouts selected are included in part B of Appendix 1.

4.7 Roof System Comparison

The roof systems were designed to resist two loading conditions: the 747 oblique impact, and the blast from an internal accident in a weapons or maintenance bay. The 500-lb bomb threat is reduced by the addition of a nonstructural burster slab above a soil cover. The blast load consists of the initial shock wave and its reflections plus the quasistatic pressure.

Three types of roof systems were considered:

1. One- and two-way reinforced concrete slabs,
2. Reinforced concrete arches with a relatively low rise/span ratio,
3. Reinforced concrete I-beam sections with soil fill between the top and bottom flanges.

As a comparison, each type of roof was designed to resist the 747 oblique impact crash on a span length of 40 feet. Details of these designs are contained in Appendix 6.

The concrete I section would provide a relatively thin top and bottom slab joined by stiffeners. The I section would resisc the 747 impact. The top slab would force the 500-lb bomb to detonate, with the bottom slab resisting the blast transmitted through the soil. Although this appeared to be a promising system, the forming and construction would be difficult. Also, terrorist entry may prove to be quite easy. After the upper slab of the I section is breached, a charge located in the earth fill would easily destroy both the top and bottom slabs of the I resulting in a large entry hole. This concept was therefore discarded.

The arch section was designed with an arch rise of only five feet since it was felt that any greater rise would be prohibitively expensive, especially for any buried storage facilities. While the design would result in some savings in concrete and steel, it was felt that these savings would be more than offset by increased forming expenses and increases in the exterior wall strengths to resist the horizontal support reactions. The reinforced concrete slab concept was thus selected.

The blast pressures from an internal explosion are applied uniformly to any slab area over a weapons or maintenance bay. The 747 loading discussed in Section 4.1 is for a normal impact. Because this is not a credible event, a 30° oblique impact was considered. The component of force normal to the slab surface is used in analysis. It is recognized that the time and magnitude of the entire loading function of an oblique impact is different than that for a normal impact. However, these data are not available and the force component for the 30° impact was therefore considered. Application of the nominal 747 oblique impact loads varies with slab dimensions and placement of the roof with respect to the ground surface. For aboveground roofs (or those with a burster slab and minimal earth cover), the impact pressures are applied directly to any one-way slabs of less than 44 feet (the impact area being an oval 44 feet by 22 feet in size for an oblique impact). For two-way slabs greater than 44 feet x 22 feet in size, the total impact loads are divided by the roof area to produce a uniform load. In the case of buried structures, the applied surface load was distributed with depth using the Boussinesq theory, and the maximum force on the roof was determined. This force was then divided by the roof area to produce a uniform pressure. Pressure attenuation with depth is also presented in Appendix 6. The slab thickness in all cases must be compared with the minimums required for the 500-lb bomb. This is for either an aboveground condition (500-lb burst in air) or an underground condition (500-lb bomb burst in soil).

Material properties, allowable deflections, and other section properties used in the roof designs were as follows:

concrete crush strength $f_c' = 4000$ psi
steel dynamic yield strength $f_{dy} = 72{,}000$ psi
maximum rotation - 1-way slabs
internal blast 1°
747 impact 2°
maximum deflection - 2-way slabs
internal blast $\Delta = 1/2$ (short span) tan (1°)
747 impact $\Delta = 1/2$ (short span) tan (2°)
minimum bar spacing 9 in. c-c
minimum reinforcement areas as prescribed in Table 5-1 of TM5-1300 (Ref. 2-11).

Two-way slabs are designed such that the total moment capacity along each edge is the same. All slabs have fixed supports, which means that the external walls must have the same moment capacity as the connected roof slabs.

5.0 CONCEPT DESIGNS

Once the six layouts were chosen, as described in Section 4.6, we began to develop the six layouts into concepts. The following items were considered during the concept design:

- Siting aboveground, mounded, or below ground
- Exterior wall and roof design
- Foundation design
- Entry systems arrangement
- Interior wall design
- Interior blast door design
- Air handling system arrangement
- Chemical defense system details.

The design arrangement of the above items is impacted directly by the various considerations which were discussed at length throughout Section 4.0. These technical considerations and the solutions proposed were incorporated in the design of the six concepts. This section will describe how the various technical considerations were addressed in establishing the six concepts.

The blast design of the various weapons bays and maintenance bay for an accidental interior detonation is described in Section 5.1. The exterior superstructure design is affected by the various exterior threats, and the resulting design is described in Section 5.2. Because of the chemical defense requirements and the need for total containment of an accidental explosion, the mechanical system poses a special design problem. The solution to this problem is described in Section 5.3. With the layout and structure of the six concepts established, loadout times and equipment needs can be addressed. This is done in Section 5.4. Similarly, in Section 5.5 the expected terrorist entry times are discussed and summarized. Once all design parameters are investigated and the concepts have evolved, design drawings and cost estimates can be made. These are discussed in Section 5.6.

5.1 Bay Design

Three requirements were placed on the design of the weapons and maintenance bays in case of an accidental explosion:

(1) No sympathetic detonation of other weapons

(2) Total containment of blast

(3) Reusability of explosive debris and explosive products.

At the beginning of the project effort, the Government sponsor determined that the explosion scenario for weapons bays would include detonation of the weapon while in the stored position with any blast doors closed. An accidental explosion during transport into or out of the weapons bay was not considered as an accident scenario. Certainly total containment would not be possible while munitions are being moved and the blast door is open. One could propose a double blast door arrangement where one is opened, the munition is advanced between, the first door closed, and then the second door opened. Besides being an operational inconvenience, if a detonation were to occur while between the two closed doors, the quasistatic loads would be very large for the small volume and failure would occur with containment still not provided. An additional consideration during transport is the variety of positions where munitions are not separated by dividing walls. Sympathetic detonation is possible. The explosion scenario in the maintenance bay was treated similarly. Only one munition is involved. The explosion would occur while the maintenance door is closed. The charge can be located anywhere inside the maintenance bay except for a minimum standoff of 3.0 feet from the center of the charge to any wall surface. Transport is again not considered.

This section describes how the three requirements for weapons and maintenance bays were fulfilled for the four bay designs described in Section 4.5.

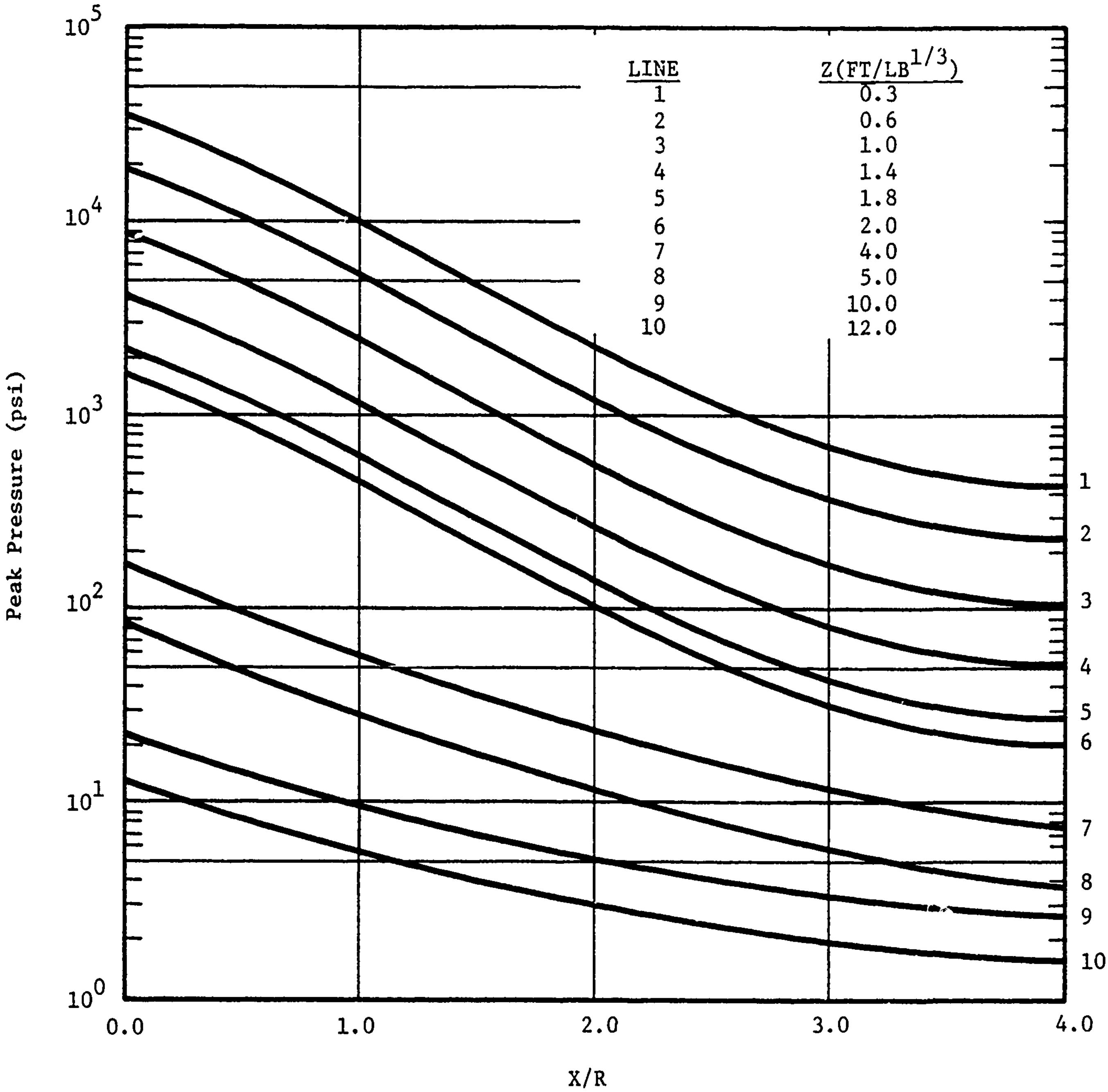
5.1.1 Blast Loading

When an explosion occurs inside a chamber, the interior surfaces experience a pressure history which is typically divided into two distinct phases: shock loading and quasistatic loading phases. These two phases are typically

predicted separately in blast analyses. The first phase consists of a very short-duration, high-pressure pulse followed by several reflected pressure pulses. This shock loading phase is a function of charge weight, standoff, angle of incidence, and location and proximity of nearby reflecting surfaces. The second phase, called quasistatic, is a longer-duration pressure pulse whose peak magnitude is a function of charge weight, room volume, and available vent area. This process is described in greater detail in Ref. 3-15.

Shock Loading - The shock pressure, impulse, and duration were calculated using methods described in Ref. 3-15. Because the structural design of the blast walls and roof assumed one-way action, the shock calculations were made for a strip running across the short span of the individual slabs. The charge position in storage, as discussed earlier, was used for shock calculations for walls. One charge height was considered with the center of the charge 1.5 feet in the air. As with the walls, the same charge position was considered for the roof and door. Shock loads calculated are summarized in Appendix 5. The shock loads were determined using the air blast curves shown in Figures 5-1 and 5-2 for pressure and specific impulse. A 1.75 reflection factor was applied to account for the several shock reverberations within the room, as suggested in Ref. 3-15.

Quasistatic Loading - The quasistatic peak pressure and duration were calculated using methods presented in Ref. 3-15. The quasistatic loads are the same for walls and ceilings. The dividing walls are loaded from all sides and, therefore, the resultant is a zero pressure when bending response is considered. The duration of this phase depends upon charge weight, room volume, vent area, and mass of the panel covering the vent openings. Because walls, the roof, and door will not fail, these were not considered for vent area. The only vent area provided is the supply and return air ducts. Because the area of these ducts is extremely small compared to the room volumes, the pressure is considered as static. Quasistatic peak pressures are given in Appendix 5. Figure 5-3 was used to predict quasistatic pressure.

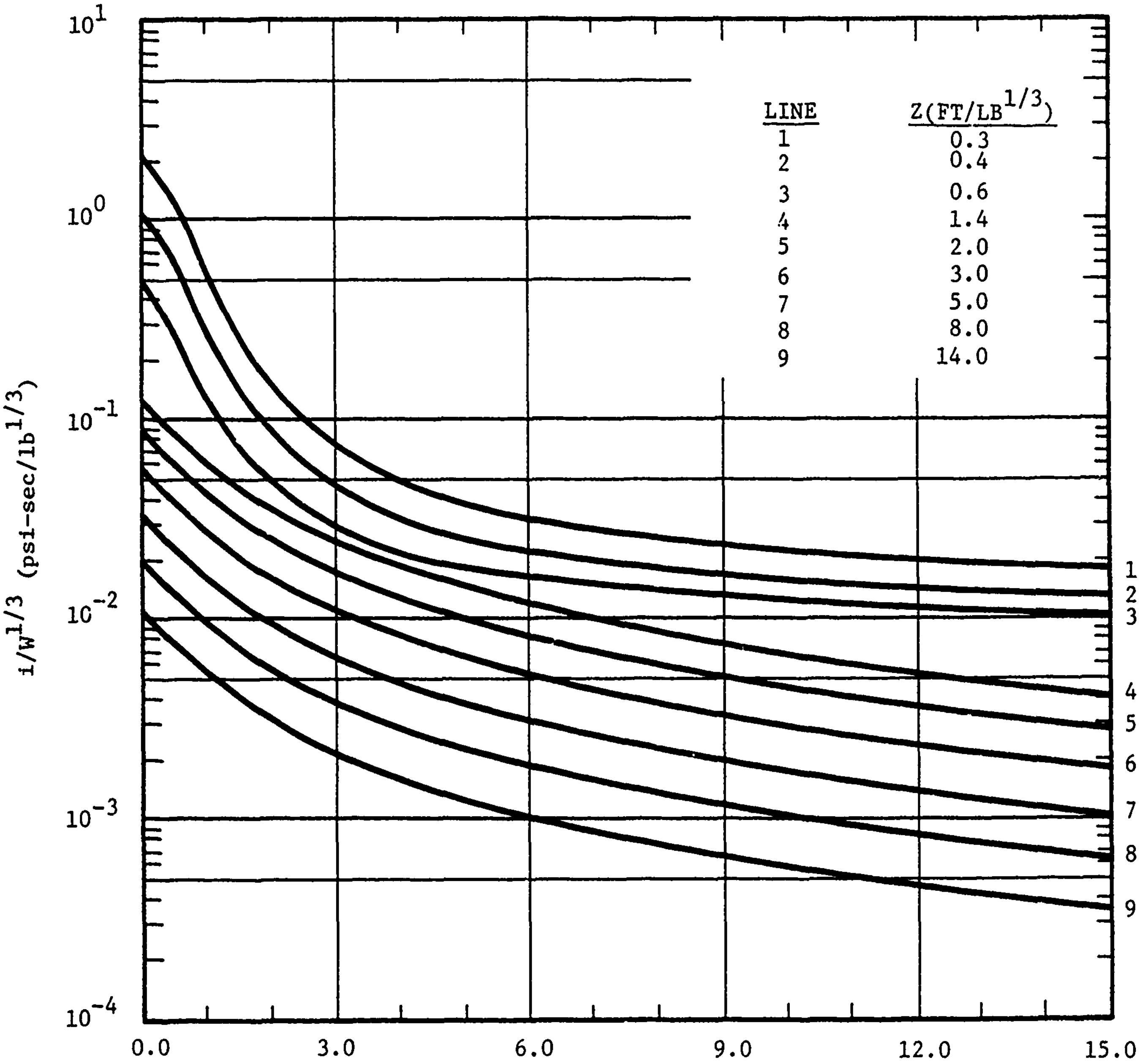


R = perpendicular standoff distance from charge to surface

Z = scaled R

X = Distance along surface from perpendicular intercept point.

Figure 5-1. Blast Pressure



i = impulse
W = charge weight
R = perpendicular standoff distance from charge to surface
Z = scaled R
X = Distance along surface from perpendicular intercept point

Figure 5-2. Scaled Blast Impulse

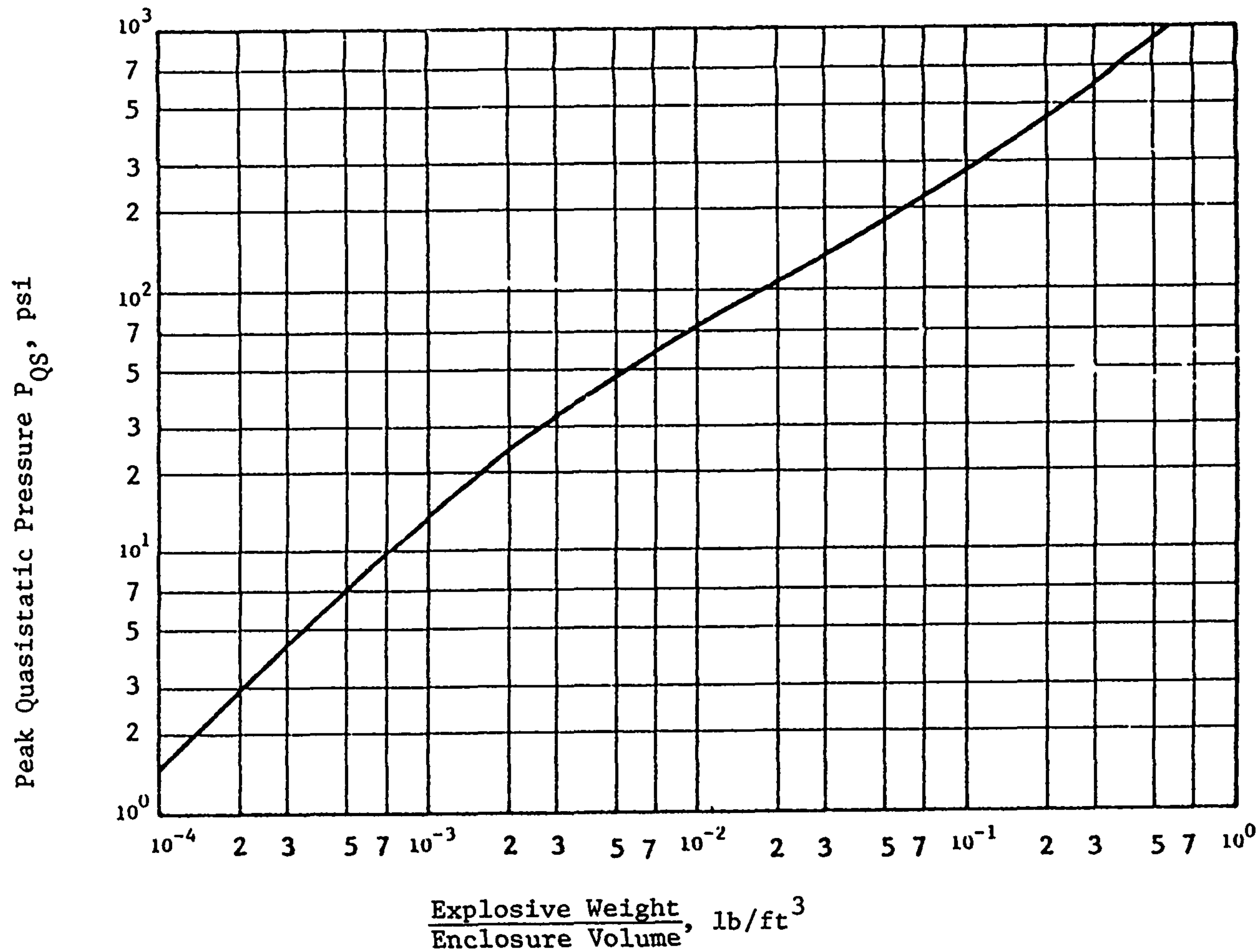


Figure 5-3. Quasistatic Pressure

5.1.2 Fragment Loading

The fragment hazard was selected as described in Section 4.5 and Appendix 7. It was determined that the minimum acceptable material thicknesses to prevent fragment perforation are:

Concrete = 10 inches
Steel = 1.6 inches.

These material thicknesses will stop a chunky steel fragment traveling 3,000 ft/sec with a weight of 0.4 lb.

5.1.3 Structural Design

The weapons and maintenance bays were designed to meet the requirements of no sympathetic detonation, total containment, and reusability. The first item, no sympathetic detonation, is accomplished by providing a dividing wall between storage compartments within a bay as described in Section 4.5. In that section, "typical" dividing walls were evaluated, and it was determined that a reinforced concrete wall is the most economical for this application. Spall plates are not necessary. Total containment is provided by reinforced concrete walls and roof slabs and by blast-resistant doors. Controlled venting is allowed to proceed through the supply and return vents. This vent system is completely described in Section 5.3. Reusability of the weapons bay is guaranteed by limiting response to small deflections. The exceptions to this are the dividing walls which are considered expendable.

All reinforced concrete design followed methods described in TM5-1300 (Ref. 3-11) and Biggs (Ref. 3-16). The designs are based on 4,000 psi compressive strength concrete and Grade 60 reinforcement. Flexural bar, lacing reinforcement, stirrups, and temperature/shrinkage steel requirements are determined. Additional reinforcement is necessary to carry tension loads from adjoining member support reactions, but was not determined under this project effort as this is a design detail. Diagonal bars are required at all corners,

which will be haunched, to transfer the high shear forces at the top and base of the walls. Again, these details are not determined for this concept analysis. The rebar schedule for all six concepts is included in Appendix 5.

The blast door design followed methods described in the Suppressive Shields Manual (Ref. 3-27) and in Biggs (Ref. 3-16). The design assumed A-36 steel.

Both the steel and concrete design were made for dynamic response to the predicted transient blast loads. A static equivalent analysis was not made. Design details are discussed below.

Wall Design - The weapons and maintenance bay blast walls are 24-inch-thick laced reinforced concrete, designed for approximately one degree of rotation. This thickness is well in excess of that required to stop fragments. The one degree of rotation value was chosen to limit the deflection of the walls such that they are reusable after an accident. The blast walls were designed as one-way elements spanning from floor to ceiling. The walls are evaluated as fixed-fixed members. The 24-inch wall thickness allows reasonable bar sizes and spacing. The lacing runs in one direction only (floor to ceiling).

This design applies to all interior blast walls. Exterior wall design is also based on exterior threats; hence a comparison is made and the worst case is chosen. In all cases, the external threat is controlling. The reinforcement schedule for all concepts is included in Appendix 5.

Dividing Walls - As described earlier, the dividing walls are laced reinforced concrete. The design rotation was selected as 12 degrees which is satisfactory for a non-reusable structure. For the double-stacked bays and the long bays, the dividing walls are treated as one-way, fixed-fixed members. The double-stacked wall has a span of approximately 8 feet (one level) and the long bay has a span of 12 feet (room height). The one-way

design is for a representative vertical section of the walls. This design is also applicable for the dividing floor on the double-stacked concept. For the pit and maze type bays, the dividing walls were evaluated as cantilevers since they do not extend to the roof slab. The cantilever span was chosen as five feet. All of the dividing wall designs resulted in 12-inch-thick members which allow reasonable bar sizes and spacing and prevent fragment perforation.

Roof Slab - The roof slabs can be exposed to both the internal explosion and external threats. A comparison was necessary to determine the exterior threat (discussed in Section 5.2), then checked for the interior blast loads and a one-degree rotation. Only in the two-story structure (reference layout design 10-1 in Appendix 1) where the weapons bays are protected by an upper floor, did the internal loading control. This layout included the double-stacked bay. The roof slab was evaluated as a two-way responding member with fixed supports on all four sides. The design resulted in a 36-inch-thick slab which is sufficient to stop the fragment threat and results in reasonable bar sizes and spacings.

All roof slabs are exposed to the internal loads, whether the design is driven by the exterior threat or by the internal loading. On many occasions, blast-resistant designs incorporate lacing reinforcement to handle shear loads in concrete slabs. This is required in the following situations:

(1) the calculated shears are in excess of the concrete shear capacity
(2) rotations are in excess of two degrees, which is the onset of concrete cracking per TM5-1300
(3) the loading is extremely spatially concentrated
(4) when backface spall is a problem.

The roof slabs for the six concepts will not use lacing. Instead, stirrups will be provided. The slab shears due to the internal loads are carried by the stirrups. For internal loading, the design rotation is one degree.

Although the internal shock loads are spatially concentrated on the walls, the roof slabs are far enough from the detonation point that the shock loads are both spread out and reduced in magnitude. Quasistatic loads are spatially constant. The magnitude of the ceiling internal loads is not sufficient to cause spallation. The same justification is discussed for the exterior loads in Section 5.2. A summary of all reinforcement bars is given in Appendix 5.

Blast doors - The blast doors to the various weapons bays and maintenance bays were designed for nominal dimensions of 7 feet wide by 9 feet high. The loads for all bays--weapons and maintenance--were similar and resulted in the same design. The door includes a single two-inch thick, solid steel plate. The blast door was designed by choosing a standard plate thickness greater than the minimum required for fragment perforation. Two plate thicknesses were evaluated--1.6 inches and 2.0 inches. Typically in blast-resistant design of plates, some plastic deformation is allowed such as suggested in Ref. 5.1:

- reusable design: $\theta_{MAX} = 2°$ and $\mu = 5$
- non-reusable design: $\theta_{MAX} = 4°$ and $\mu = 10$.

The 1.6-inch plate resulted in $\theta = 4.8°$ and $\mu = 1.1$. The 2-inch plate resulted in $\theta = 2.6°$ and $\mu = 0.73$. Although both designs have values of $\theta > 2°$, it was concluded that either was sufficient for a reusable design because of the small values of μ. The 2.0-inch plate was chosen because it provides additional safety for fragment perforation beyond the minimum. In addition, the response is elastic. Finally, a large part of blast door construction costs are in the labor to construct, and the difference in material costs between the 1.6- and 2.0-inch plates is not considered expensive. Hinges are provided to carry the dead weight of the door during opening or closing. The door is simply supported on three edges by the jambs. The floor edge is free. No "step ups" are allowed at the floor because of equipment travel. During rebound, the door will tend to unseat. Rebound pins are provided which slide into and out of the door jamb, operated by the hardware which is a steering wheel type mechanism. The rebound pin requirements to resist the rebound shear

are 14 one-inch-diameter pins evenly distributed about the three sides. The door jamb is formed into the concrete and is lined with 1/2-inch plate throughout. Because the jamb carries the support loads of the plate when responding with the loading, anchor bolts from the jamb extending into the concrete are necessary. Twenty 1.5-inch diameter bolts evenly distributed about the jamb are sufficient. Enhancement of the reinforcement on each side of the door is necessary but was not calculated in this concept level analysis.

5.2 Superstructure Design

Before the superstructure, or exterior shell, of the various concepts could be designed, the siting aboveground, below ground, or mounded had to be determined. Unlike the internal explosion design described in Section 5.1, the external loads are dependent on the siting. As discussed in Section 4.6, six layouts were selected for the basis of designing six concepts. The layouts are illustrated in Appendix 1. These layouts are not illustrated in this text or extensively described at this point. This is because, as the structural analysis proceeded, along with interchange with the AE subcontractor to this program, modifications to the layouts were made to accommodate the design of the structure to resist the exterior threats and to accommodate the mechanical systems necessary for the proposed layouts. This selection process is described in Section 2.0. The final concepts after all preliminary design iterations are discussed and illustrated in Section 5.6. This section describes the steps in superstructure design.

Of the six layouts chosen for further evaluation, three were compact one-story structures, one was a compact two-story structure, and one was a spreadout one-story structure. In order to evaluate the effect of overburden on the external threats, three conditions were selected: a surface structure with no earth overburden, a structure with approximately 19 feet of earth cover, and a structure with approximately 24 feet of earth cover. These three conditions were chosen to provide a variety in the designs for the 500-pound bomb, 747 impact, and the terrorist threat. The loads on a surface structure due to any of the threats would be greater than for the buried conditions, but excavation costs are less for surface structures. The depths of both 19 feet and 24 feet are below the maximum path length of a 500-pound bomb in soil, as discussed in Section 4.1. The 15-foot penetration is chosen here for use. In addition, a bomb trajectory in soil is not straight, having a turnup toward the end of its trajectory length, particularly for an oblique impact. Because of this, the maximum below-surface depth of a 500-pound bomb is set at 13 feet (with a two-foot turnup) and this distance is used to determine the standoff

to the roof slabs of buried structures. This bomb penetration depth assumes no surface slab above which would reduce penetration.

The design process of the exterior shells of the concepts followed the following steps:

(1) Determine roof slab thickness for the 500-pound bomb using Figure 4-6 and the standoff

(2) Use the slab thickness determined in (1) as a minimum in the response analysis for the 747 loads. Size rebars for that thickness

(3) If a thicker slab will result in more reasonable rebar sizes and spacings for constructability, evaluate several slab thicknesses greater than that chosen in (1)

(4) Select slab thickness and reinforcement

(5) Compare (4) with internal blast requirements for slabs over weapons and maintenance bays and select worst case

(6) Select exterior wall slab thickness and flexural reinforcement to match the adjoining roof slab

(7) Compare exterior walls with the internal blast requirements at the weapons and maintenance bay walls and select worse case

(8) Analyze all wall and roof slabs for the 300,000 pounds of HE at 100 meter surface burst threat.

It should be noted that the earth-covered situation can be either below ground, mounded, or a combination. The analysis that followed would have the same result for any of the three conditions.

As the six layouts were formed into six concepts, modifications to the floor plan and ceiling heights were made. The above design steps were repeated several times before the final concept design was completed. The design in Appendix 5 includes only the final design calculations and does not represent the many preliminary iterations leading up to the final design. For all calculations, 4,000 psi compressive strength concrete and Grade 60 reinforcement was assumed.

5.2.1 500-pound Bomb Considerations

Figure 4-6 indicated the minimum slab thickness with standoff required for a 500-pound bomb either for an explosion in air or in soil. As shown, if a direct impact is allowed as in the aboveground case, a very thick section is required. In Section 4.1 it is also indicated that a two-foot slab of concrete can defeat the bomb if backed by a layer of soil. An unbacked slab would have to be as thick as four feet to provide the same protection. The soil-backed burster slab was chosen to: 1) minimize the burster slab requirement, 2) provide built-in standoff to the roof slab, and 3) help defeat terrorist attack. For this condition, a 48-inch roof slab is necessary. This typical cross section is shown in Figure 5-4. Other possibilities for damage to the structure by the 500-pound bomb are direct impact of the sidewall and a near miss. The near miss could enter the earth and follow a path which eventually turns upward with the bomb coming to rest directly under the floor slab. To provide protection from these threats, the weapon can be prevented from reaching the sidewall or floor slab. This protection can be provided by a sidewall burster slab which is spaced and parallel to the wall. This slab would extend down below grade to also protect the floor. Alternatively a skirt burster slab could be provided at least 15 feet out. A much simpler system would be to provide a slant wall as shown in Figure 5-5. The choice of the slant wall was not based on the 500-pound bomb threat alone. The 747 impact also played a role in this selection and will be discussed in Section 5.2.2.

Protection to the below-ground concept is provided by burying the structure beyond the 13 foot maximum depth that the bomb can reach (different than the 15 foot total path length as described earlier). Three depths were finally considered in the concept designs. They are listed in Table 5-1 as well as the minimium slab thickness per Figure 4-6. The surface conditions discussed above are also included. These slab thicknesses are provided by the references cited without specifying minimum reinforcement. The reinforcement will be set by the aircraft impact loads as described in the next section, 5.2.2. This reinforcement is expected to be larger than for standard construction and should meet or exceed any minimum considered during the bomb

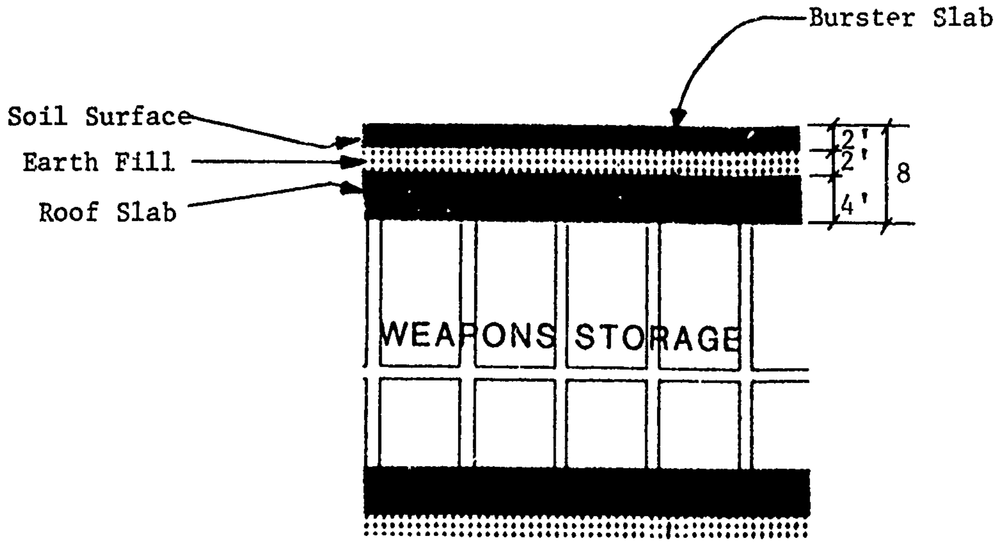


Figure 5-4. Typical Burster Slab for Aboveground Structure

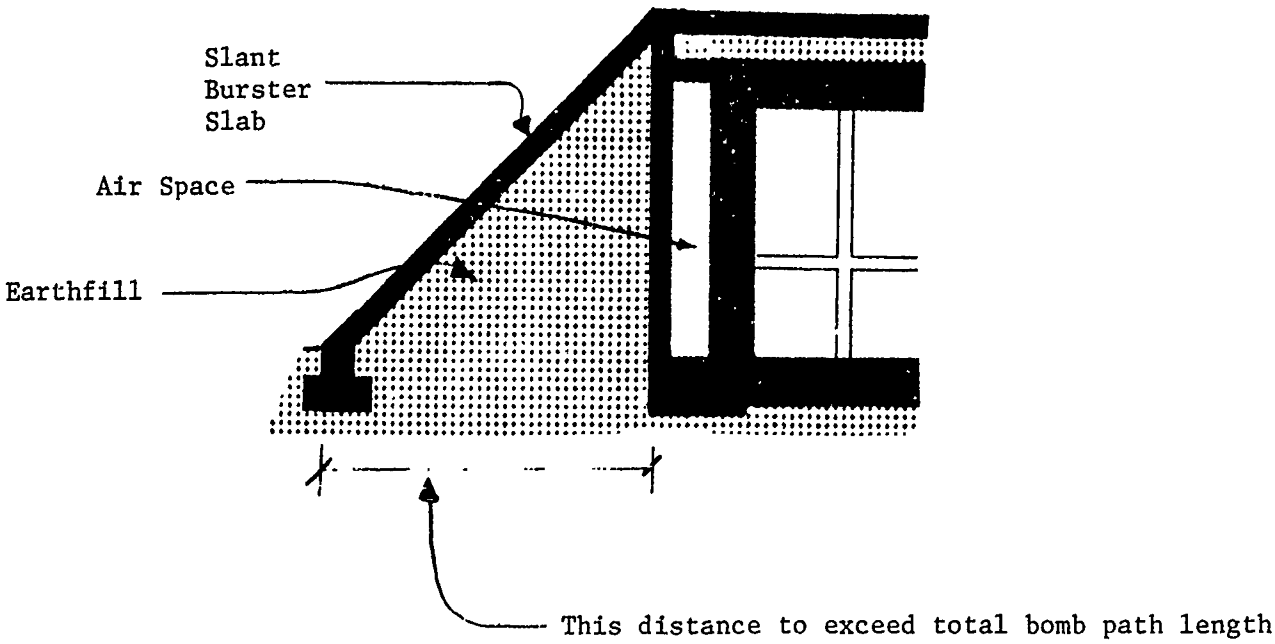


Figure 5-5. Slant Wall Burster Slab Typical for Aboveground Structures

breaching tests on which the minimum slab thickness in Table 5-1 is based. The type of shear reinforcement is also not specified for the slabs. It is assumed that stirrups are acceptable.

Table 5-1

Minimum Roof Thickness to Prevent Breaching by the 500-lb Bomb

Depth from Surface to Top of Roof Slab (ft)	Minimum Slab Thickness (in.)
Surface	48
16	30
19	24
24	18

5.2.2 Aircraft Impact

The 747 impact is discussed in Section 4.1 including the pressure history and the effect of soil overburden. The assumed impact condition considered for concept design is for an oblique impact. The reinforced concrete design followed methods described in TM5-1300 (Ref. 3-11) and Biggs (Ref. 3-16). Flexural bar, stirrup, and temperature/shrinkage steel requirements were determined. Most of the functional areas are nearly square, and two-way slab design was assumed. The slabs are considered fixed on all four sides. The corridors and the load dock roof slabs require one-way design fixed at both ends. The roof slabs for the six concepts will not use lacing. Instead, stirrups will be provided to resist the slab shears. Stirrups are required in two directions for two-way slabs. For one-way slabs, the stirrups are required in one direction only. The slab design is made for a maximum of two-degree rotation. This value was chosen for two reasons. First, for large spans, rotations greater than two degrees result in large center span deflections. This would represent an operational problem for removal of weapons after the aircraft impact. For large rotations the structure would not be reusable in the future. Second, limiting the rotation to two degrees or less prevents

crushing of the concrete that would occur for larger rotations. This is important because stirrups can be used as opposed to lacing, as discussed earlier in Section 5.1.3. The pressure of the aircraft impact does not cause spall. The loading is concentrated over the area of impact. This area is on the order of the typical slab sizes used in the various concepts; hence, although the load is concentrated relative to the entire facility, it is well distributed for an individual slab. For all of these reasons, stirrups are acceptable in place of lacing. Stirrups are preferred for both material cost and (especially) labor costs.

The roof slabs were evaluated for several thicknesses with the minimum set by the 500-pound bomb requirements provided in Table 5-1. It was determined that the combination of slab thickness and burial depths described in Table 5-2 result in reinforcement bar sizes and spacings which are reasonable for constructability. A complete reinforcement schedule is provided in Appendix 5 for all six concepts.

Table 5-2. Roof Slab Designs

Overburden Depth (ft)	Slab Type	Slab Thickness (in.)
Surface	two-way	48
Surface	one-way	72
16	two-way	36
16	one-way	48
19	two-way	36
24	two-way	36
24	one-way	36

The slabs are evaluated for fixed supports. The moment resistance to provide the fixed boundary condition is supplied by adjacent roof slabs and interior walls everywhere except at the exterior walls. The exterior walls must be designed to provide at least as much moment capacity as the

adjoining roof slab. (See Appendix 5 for a summary.) Note that an aircraft impact directly into the sidewall is not discussed. As mentioned previously and described in Figure 5-5, a slanted slab is provided for all aboveground structures. If an aircraft were to skid into the side of the structure, it would be ramped up and onto the top of the structure. If this were not present, a normal impact of the sidewall would be possible. It was determined that a normal impact to the walls, or roof for that matter, would represent a very substantial threat. A much more massive structure would be required for this condition, and hence is avoided.

5.2.3 Large Explosion

The large explosion threat was specified as a 300,000-pound surface blast at 100 meters. The structure was evaluated for the blast loading and determined to be considerably overstrength compared to that needed for either the 500-pound bomb or the aircraft impact. Hence, this threat was not a driving design parameter for the concept superstructure.

The two load docks were purposely positioned on opposite sides of the structure, and the two driveway ramps were faced in opposite directions on each concept so that the 300,000 pound explosion threat could not load both entrances simultaneously. This allows each door system to be designed with a 12-degree rotation constraint since one door will always survive. The door receiving the loading may be unreusable following the explosion, but it will have prevented harmful blast effects from entering the structure. Detonation of the 300,000 pounds of explosive 100 meters away from the structure will not cause any ear or lung damage to personnel inside the structure.

5.2.4 Subsurface Design

Following are the foundation concepts resulting from preliminary calculations made using the approach discussed in Section 4.4.3. Again, these calculations were based upon commonly known theories of soil mechanics found in such books as Essentials of Soil Mechanics and Foundations by David F. McCarthy, Foundations Analysis & Design by Joseph E. Bowles, and Foundation

Engineering Handbook by Winterkorn & Fang (Refs. 4-22, 4-25, 4-20). Concrete design of the mat was based upon the ultimate strength method found in Design of Concrete Structures by Winter & Nilson (Ref. 4-26).

Obviously, much of the design, especially settlement, is highly dependent on the actual soil conditions at the building site. These conditions are unknown at this time and a geotechnical investigation would be needed. The calculations were made based upon certain assumptions; therefore, the results obtained reflect these assumptions. These results should not be considered as the only solution. The calculations serve only as a guideline for the methodology involved in establishing foundation concepts. Both the calculated results and possible alternatives based on altered factors will be discussed.

Those assumptions used in the foundation design and analysis are as follows:

- location of water table at ground level
- infinitely deep bedrock
- soil is dominantly clay
- depth of clay layer = 50 feet
- unit weight of dry clay γ_{dry} = 100 pcf
- unit weight of saturated clay γ_{sat} = 120 pcf
- unit weight of reinforced concrete = 150 pcf
- cohesion of clay c = 500 psf
- bearing capacity factor Nc = 5.14
- void ratio e_o = 1.20
- f'_c = 3 ksi, f_y = 60 ksi
- 3-ft-thick foundation mat

For the aboveground configuration, the analysis revealed that the allowable bearing capacity of the soil was not adequate using the above assumptions (Figure 5-6a) ($q_{allow} < q'$, where q_{allow} = allowable soil bearing capacity and q' = effective pressure of the building)) It was discovered that burying the structure approximately 5 feet and adding a 12-foot skirt around the perimeter of the mat reduced the bearing problem sig-

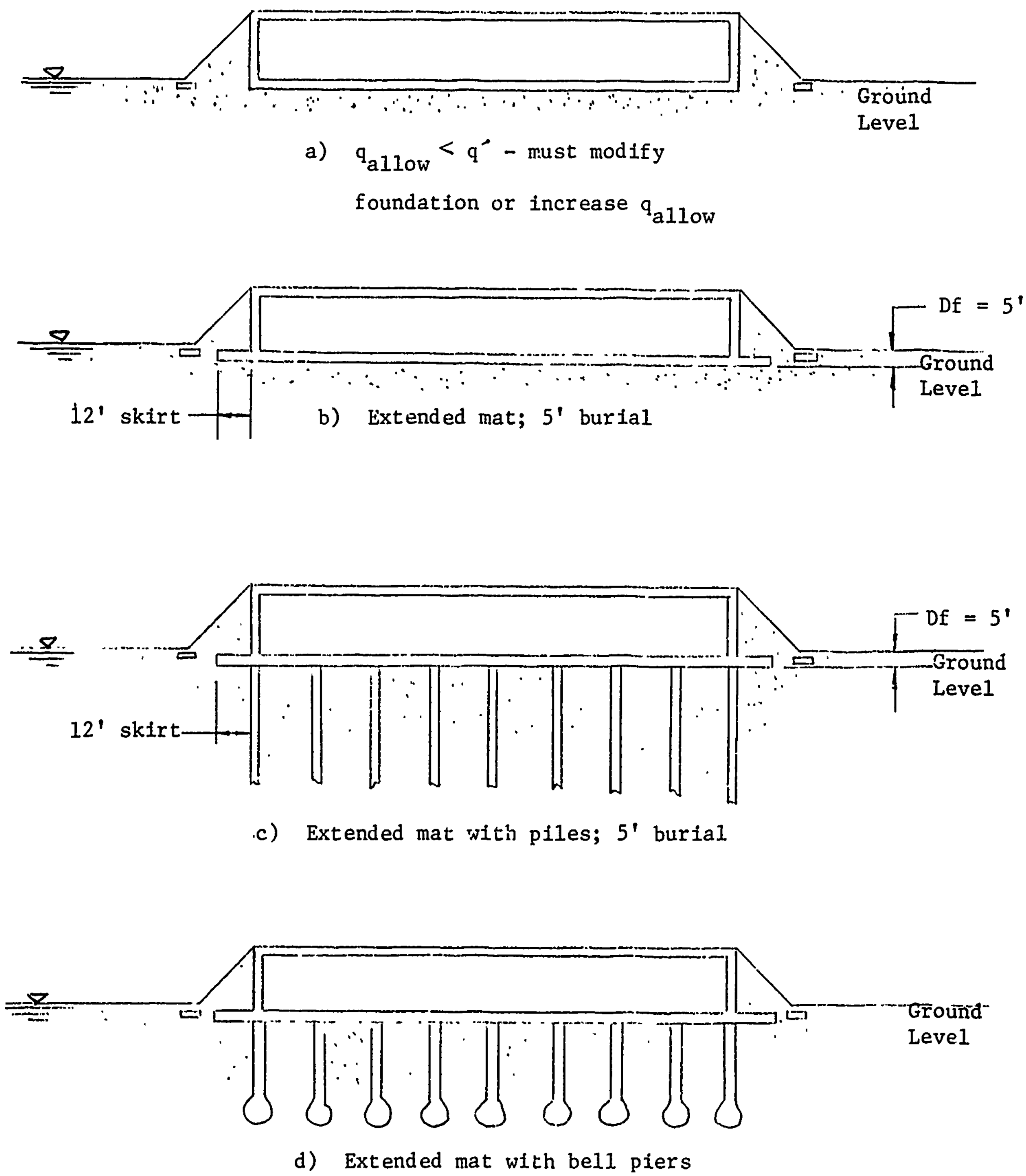


Figure 5-6. Aboveground Configuration

nificantly (Figure 5-6b). The addition of 100-2-foot-diameter friction piles to the mat would yield even more acceptable results (Figure 5-6c). The allowable soil bearing capacity may prove to be much greater and/or can be improved by soil stabilization methods. If so, the skirt and the need for burial may be eliminated. Piles or bell piers (Figure 5-6d) would probably be required in a soil containing sand such as in the Galveston area, but may not be required in an area where clay is dominant. The design was found to be capable of resisting hydrostatic uplift and loading due to hydrostatic pressure. The results from the settlement calculations are of little use since the calculations are so highly sensitive to the actual soil conditions. Settlement is not expected to be a problem.

Another foundation concept was considered for the two-level, partially buried structure. Calculations revealed that a burial depth of approximately 22 feet was required to achieve $q' = q_{allow}$ and that a depth of approximately 24 feet was required to achieve weight compensation. Since weight compensation is desirable because settlement is minimized, lowering the foundation from 18' to approximately 24' would be highly advantageous. The concept is presented in Figure 5-7. The calculations showed that no piles were required; however, depending on the actual soil conditions (e.g., Galveston area), piles or piers may be recommended. The foundation design was found to be sufficient to withstand hydrostatic uplift and loading caused by hydrostatic forces.

The third concept was for the buried configuration. Again, the floating foundation concept was utilized. A depth of dry soil and the depth of burial were calculated to where weight compensation could be achieved and where 21 feet of ground cover could be maintained. It was determined that this condition could be met by burying the structure 30 feet below ground and depositing 13 feet of saturated soil and 8 feet of dry soil above the roof of the structure. The concept is presented in Figure 5-8. Again, piers or piles may be required depending on the actual soil conditions. The design was also found to be capable of resisting hydrostatic pressure. The depths of burial and covering were developed for this one structural concept and can obviously be modified to accommodate a different structural design depending on the actual soil conditions at the site. The main objective, however, would still be to maintain weight compensation.

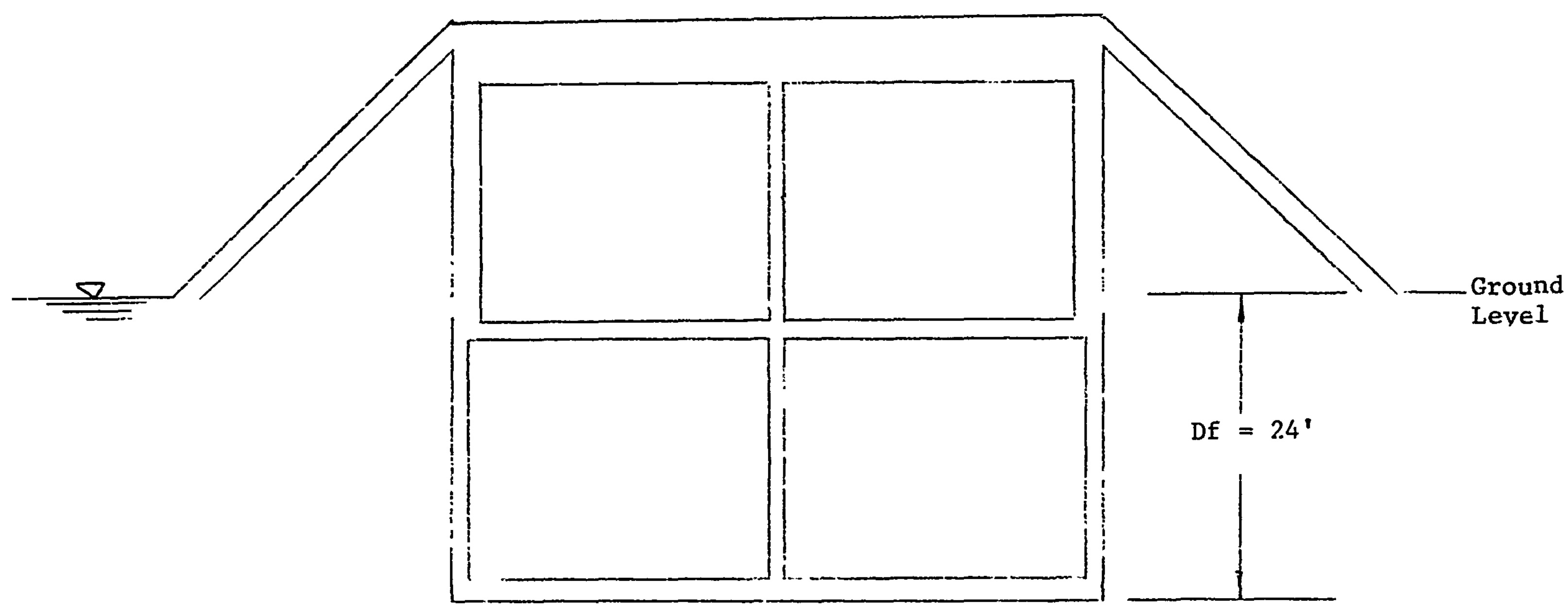


Figure 5-7. Two-Level Partially Buried Configuration

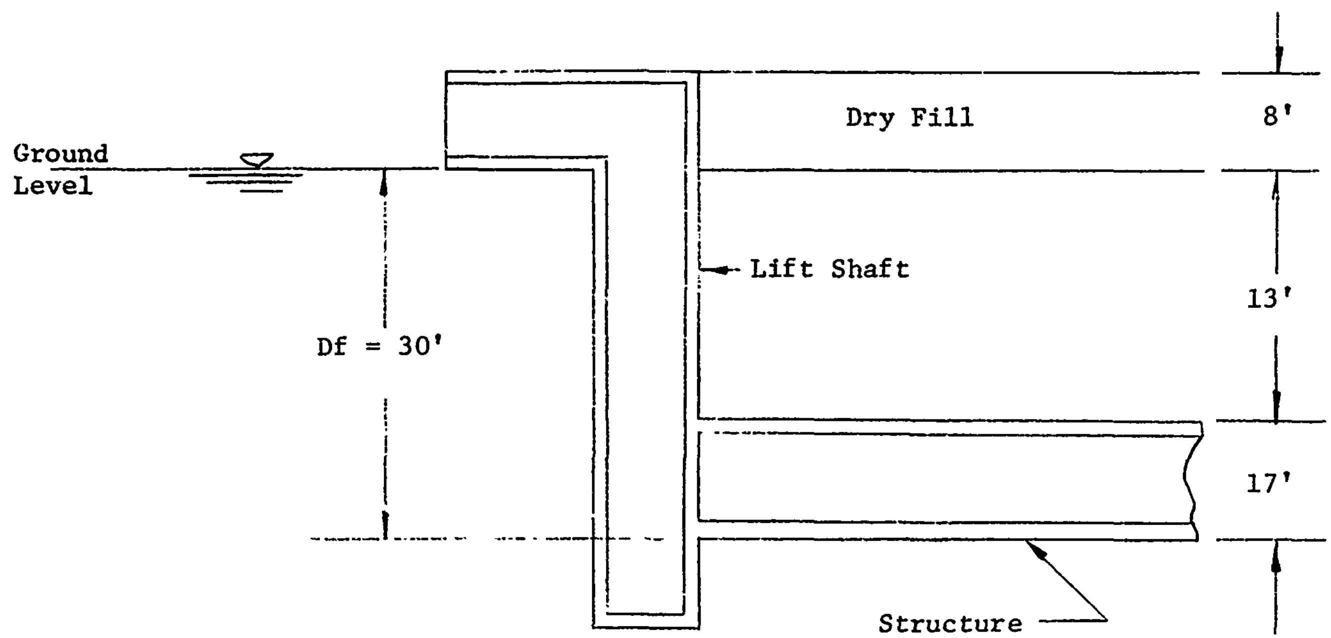


Figure 5-8. Tctally Buried Configuration

5.3 Air Handling Considerations

Airflow throughout the facility complex will be directed to accommodate the various areas in conjunction with the HVAC and chemical defense systems. T ir chases or plenums should not interfere with the building operations. For layouts which are compact and have a central connecting corridor, an air plenum can be provided above the corridor which is convenient to all areas while still maintaining a sufficient ceiling height in the corridor. Air spaces in the facility which are provided primarily for other purposes can often be made to serve a dual purpose by acting as HVAC air plenums. For example, an air space is often placed in the perimeter walls as a deterrent to terrorists. This space can also be used as a return air plenum for the HVAC system. The use of corridor plenums and exterior wall air spaces forms the basis for the air handling system for the various facility concepts. This general approach is illustrated in Figure 5-9.

If an accidental detonation of a weapon occurs inside one of the storage bays, then explosive products, weapon casing debris, and nonexplosive materials are distributed throughout the room. Blast-proof walls, roofs, and doors are provided to contain the shock and quasistatic loads. Dividing walls are provided to restrict the event to a single detonation. After the detonation occurs, the gas or quasistatic pressure and explosive residuals must be vented. Explosive residuals are defined here as explosive products, and suspended nonexplosive materials.

The air handling system provides supply and return air vents in the weapons bay. These penetrations provide a means of venting an explosion. It would be desirable to contain the explosion residuals completely inside the bay of occurrence. This could be done if blast gates were provided at all penetrations, thereby closing off the bay totally. However, venting must proceed at some point. This could be provided by a separate system which is normally closed, then opened after the detonation occurs. The vented residuals would be filtered before release. This separate system would require an air pump to move several air changes through the filters. This type of system is very dependent on fast-acting blast gates.

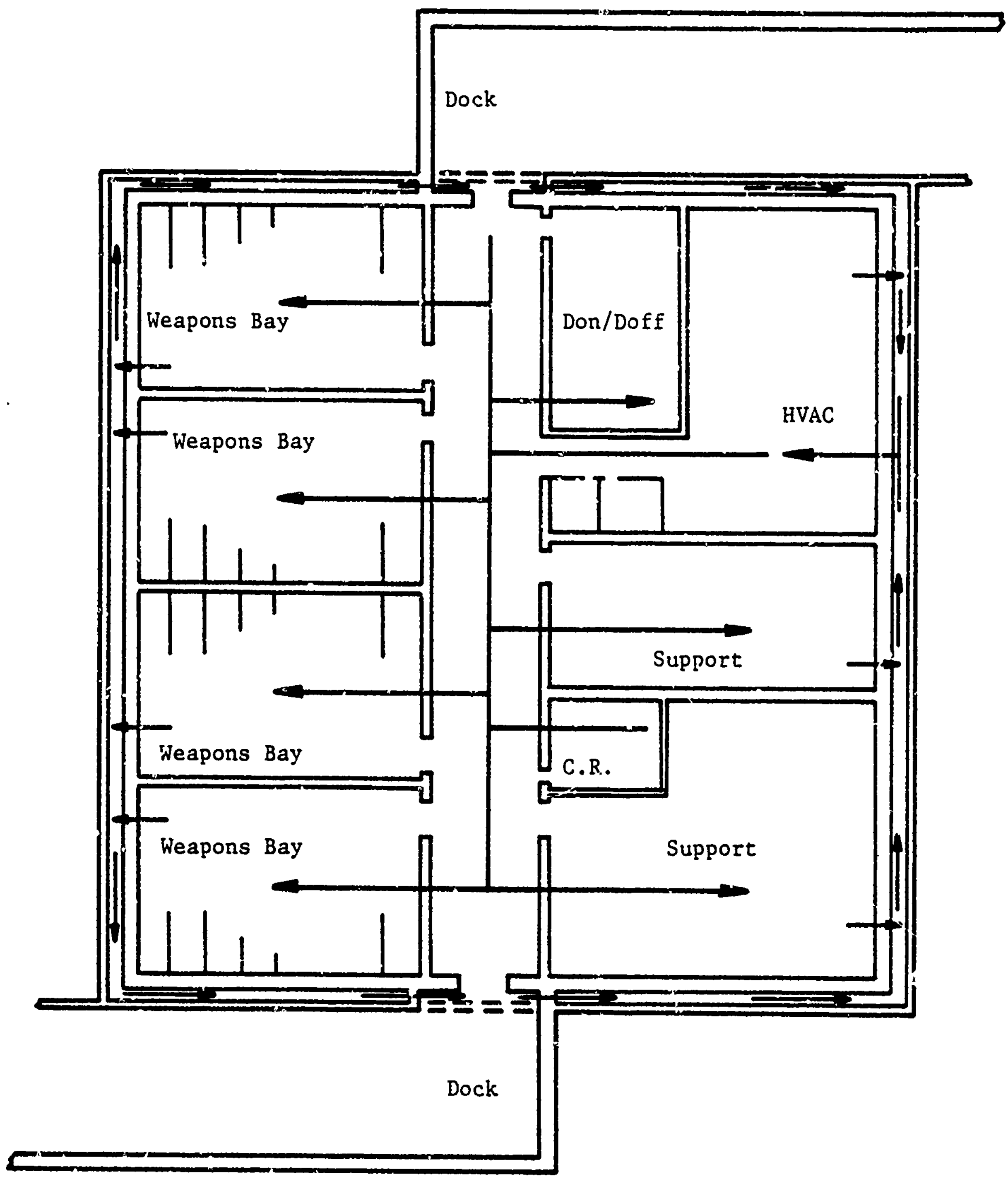


Figure 5-9. Typical Air Handling Network for Concept No. 1

Blast gates are not new, having been used at existing facilities in the U.S. and around the world. However, the blast gate system requires enough time between blast detonation and gate closure to prevent blowthrough. SwRI is not confident that this can be accomplished, and would expect some release of explosive residuals into the air plenum system and then on to other areas in the complex before closure is achieved. In addition, blast gates are expensive.

The use of exterior venting to the outside is contrary to the requirement to minimize the number of exterior penetrations for the terrorist threat. For these three reasons (need for a separate air handling system, no insurance of total containment, and cost) SwRI would not recommend the above system for providing total containment.

We would prefer to use the existing air handling system with some modifications. The concept that was adopted for use in the six facility layouts chosen in this study provides total containment of the severe overpressures within the bay of occurrence, and total containment of explosive products. This is done by providing stout grillage at the bay penetrations. A system of nested angles has proven to be a good blast-resistant or suppressive vent cover (Figure 5-10). These suppressive vents are placed on every supply and return vent throughout the facility. On the plenum side of each suppressive vent, a HEPA filter is provided. Because warehouse airflow conditions are the requirements for the weapons bays, slow movement of air is provided. This means that the air openings in the weapons bay can be small.

The sequence of events following an accidental explosion with this system would be as follows:

(1) explosion occurs in a bay
(2) the HEPA filters at the supply and return air ducts to that room are probably lost due to the blast
(3) because of the pressures in the bay of occurrence, venting would occur through the vents. This flow would be very slow because of the small vent area

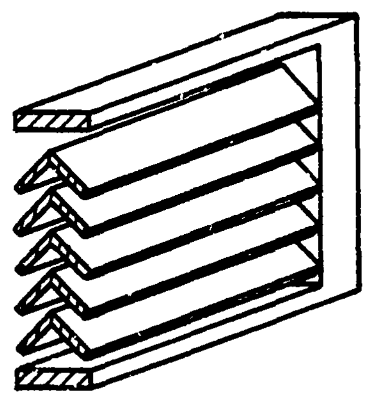


Figure 5-10. Typical Suppressive Vent Cover for Vent Chases, Cutaway View

(4) The explosive residuals would then flow into the large plenum spaces above the corridor or into the return air space in exterior walls

(5) Any venting flow into other rooms or bays is filtered through the HEPAs located at the vents to those areas

(6) The pressures in the plenums will be much lower than in the bay of occurrence. Certainly no blast shock would be present. Only a slow rising quasistatic pressure would be present at a much smaller magnitude than that in the bay of occurrence. This is because the pressure is bled slowly into the plenum and then on to other areas of the facility. The plenum walls are strong enough not to fail during this process. The pressure rise in the ventilation system due to the quasistatic pressure bleedoff is very low. No adverse effects will be experienced by personnel in other sections of the building.

In this fashion, only the bay of occurrence and the plenum system are affected in the explosion venting process. The same process is followed for an explosion inside the maintenence bay.

The following paragraphs discuss air handling considerations for six specific weapon storage facility layouts. Concept drawings of each layout can be found in Section 5.5.

5.3.1 Facility Concept No. 1

Concept No. 1 is a completely aboveground structure. The volume of the region requiring chemical protection is approximately 5.4 x 10^5 ft^3. One loading dock enters into a vestibule that can be sealed off from the main structure under threat of chemical attack. The don/doff area and CBR filter room are located adjacent to both the vestibule and the loading dock. In a chemical warfare scenario, both loading docks, the vestibule, the filter room,

and parts of the don/doff area are contaminated. The remainder of the structure is clean and at positive pressure. A forklift access route is provided between the loading dock and the filter room so that clean filters can be brought in and dirty ones removed.

Outside air enters the filter room first, where it is cleansed by passing it through the CBR filters. The airstream then enters the facility HVAC equipment housed in the mechanical/electrical room. Pressure monitors and dampers are used to keep all protected areas of the facility at a minimum of 0.3 in. H_2O above ambient outside pressure. The filtered and conditioned airstream is distributed to the various rooms and bays of the structure via an air duct network located above the ceiling of the corridor that runs through the center of the structure.

Exhaust air from all rooms and bays is channeled through an airspace located around the outside perimeter of the building. The airflow for this concept is illustrated in Figure 5-9. Most of this return air is recirculated through the HVAC system. Approximately 4,000 CFM is bled off and passed through the don/doff area to produce the cascading pressures needed in those rooms. Excess airflow through the don/doff area is vented to the outside.

5.3.2 Facility Concept No. 2

Concept No. 2 is a completely aboveground structure. The volume of the region requiring chemical protection is approximately 5.5×10^5 ft^3. As far as chemical defense and air handling is concerned, this concept is almost identical to Concept No. 1. One loading dock enters into a vestibule where weapon loadout will occur when the structure is under chemical attack. The don/doff area and CBR filter room are adjacent to this loading dock. A forklift access route is provided between loading dock and filter room. In a chemical warfare scenario, both loading docks, the vestibule, the filter room, and parts of the don/doff area are contaminated. The remainder of the structure is clean and at positive pressure.

Outside air is ducted directly into the CBR filters for removal of toxic liquids and vapors. The airstream is then passed through the facility HVAC equipment housed in the mechanical/electrical room wrapped around the filter room. The filtered and conditioned airstream is distributed to the remainder of the facility (except one mechanical equipment area) through ducts located above the ceiling in the central corridor of the facility. Pressure monitors control dampers in the ducts to maintain a positive pressure of at least 0.3 in. H_2O in all parts of the facility except the filter room, vestibule, don/doff area, and loading dock.

Exhaust air from all rooms and bays is routed through an airspace built around the outside perimeter of the building. Most of this return air is recirculated through the HVAC system. Approximately 4,000 CFM are bled off and passed through the don/doff area to produce cascading pressure levels in those rooms. Excess airflow through the don/doff area is vented to the outside. The airflow system for this concept is very similar to that for concept No. 1 as illustrated in Figure 5-9.

5.3.3 Facility Concept No. 3

Concept No. 3 is a two-story design, with one level below grade and one level above grade. The layout of each floor is essentially the same: four large bays arranged with two on each side of a center corridor. The volume of the region requiring chemical protection is approximately 6.3×10^5 ft^3. Both loading docks are aboveground. One dock is attached to a vestibule where weapon loadout will occur when the structure is under chemical attack. The don/doff area and CBR filter room are on the top story of the building and are connected to the outside through the vestibule and loading dock. A forklift access route is provided between the loading dock and filter room to facilitate filter changeout. In a chemical warfare scenario, both loading docks, the vestibule, the filter room, parts of the don/doff area, and one platform lift connecting the two levels will be contaminated. The remainder of the structure is clean and at positive pressure.

Outside air is ducted directly to the CBR filters for removal of toxic liquids and vapors. The airstream is then passed through the facility HVAC equipment housed in a mechanical/electrical room on the top floor adjacent to the filter room. The filtered and conditioned airstream is supplied to the upper floor through a plenum located above the corridor ceiling. Air is transmitted to the lower level through an air duct that leads down to a plenum space above the lower corridor. Pressure monitors control dampers in the ducts to maintain a positive pressure of at least 0.3 in. H_2O in the uncontaminated parts of the facility at both levels. Note that the floor below grade is completely uncontaminated except for the one platform lift that is used to load out weapons in a chemical environment.

Exhaust air from all rooms and bays on both floors is vented to an airspace located on the back of the bays along the outer wall of the facility. This return air space runs the full perimeter of the upper floor, whereas it runs along only two sides of the lower floor to return the weapons bay air and a single duct near one lift to return the corridor air. The airflow for this concept is illustrated in Figure 5-11. Most of this return air is recirculated through the HVAC system. Approximately 4,000 CFM are diverted through the don/doff area and vented to the outside.

5.3.4 Facility Concept No. 4

Concept No. 4 is a one-story design completely buried except for two loading docks. The volume of the region requiring chemical protection is 5.7×10^5 ft^3. The two loading docks are connected to the underground structure by platform lifts. Only one of these is used for weapon loadout in a chemical environment. The filter room and don/doff area are underground. They are connected to one of the lifts by a small vestibule area. Filters are taken in and out of the facility by a forklift that uses the platform lift to move between loading dock and filter room. In a chemical warfare scenario, both loading docks, one platform lift, the vestibule, the filter room, and parts of the don/doff area will be contaminated. The remainder of the structure is clean and at positive pressure.

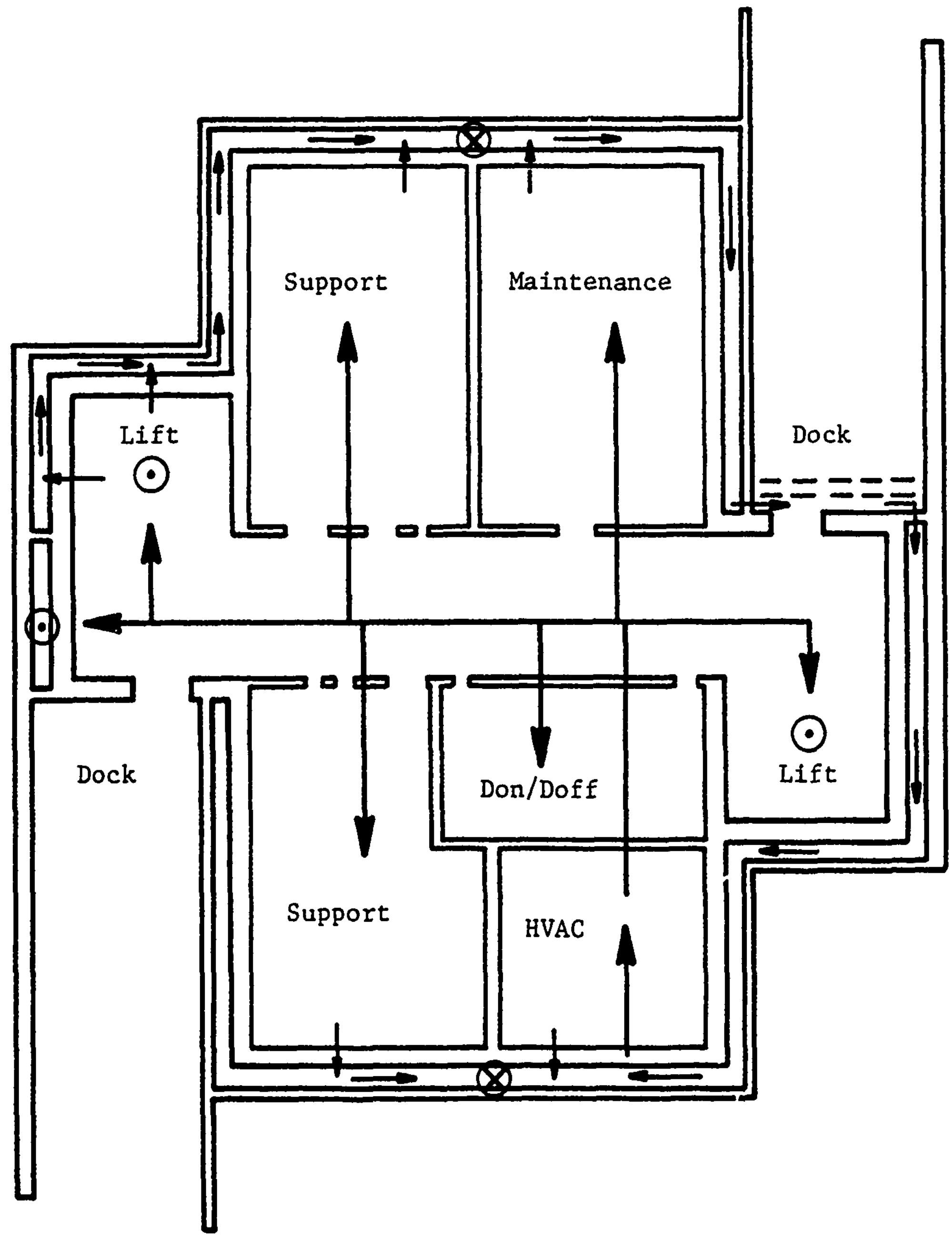


Figure 5-11A. Airflow Network for Concept No. 3 Above Grade

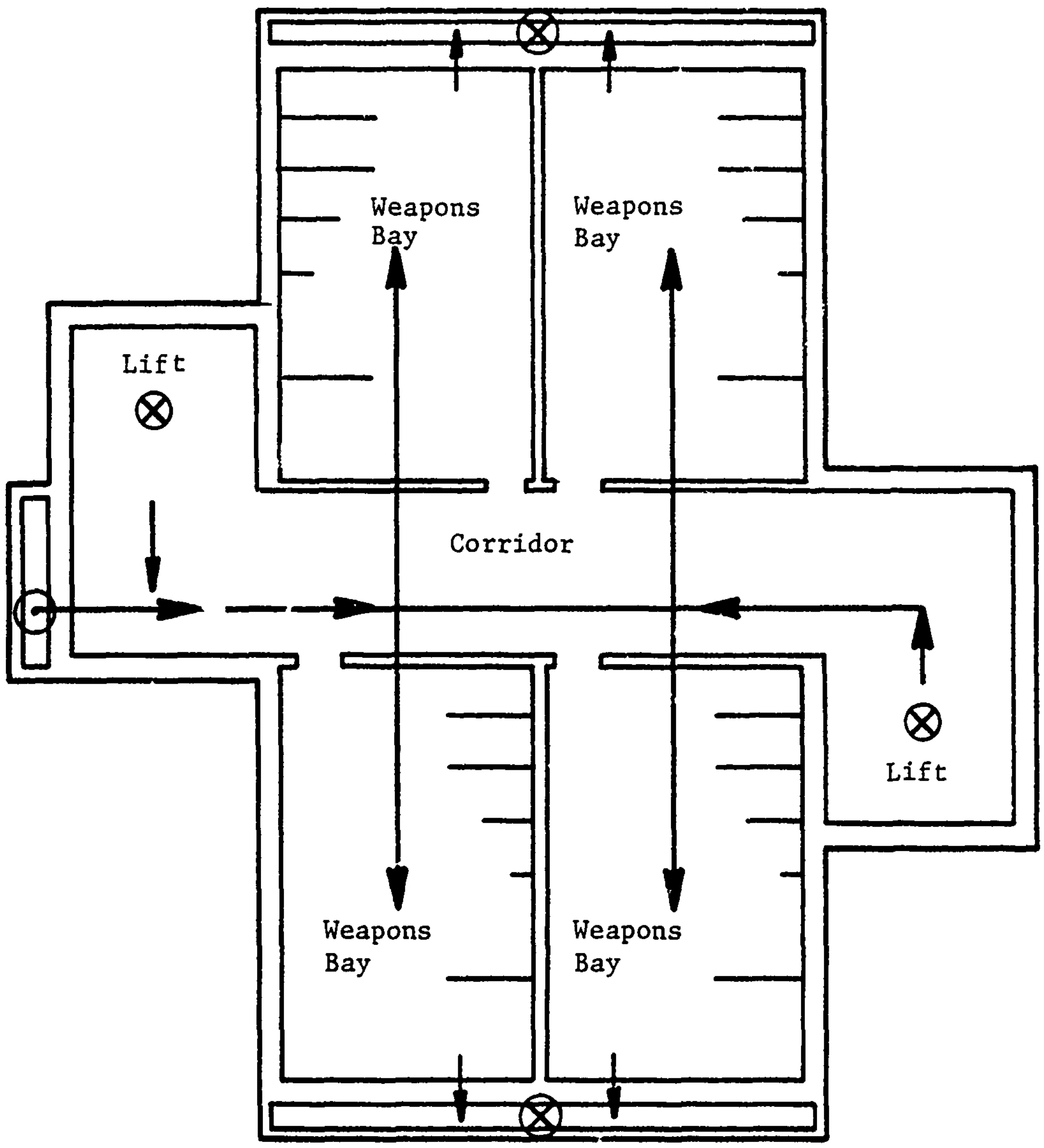


Figure 5-11B. Airflow Network for Concept No. 3 Below Grade

Outside air is ducted directly to the CBR filters for removal of toxic liquids and vapors. The airstream is then passed through the HVAC equipment housed in a mechanical/electrical room adjacent to the filter room underground. The filtered and conditioned airstream is distributed to the remainder through ducts located above the ceiling in the central corridor of the facility. Pressure monitors control dampers in the ducts to maintain a positive pressure of at least 0.3 in. H_2O in the uncontaminated parts of the facility.

The return air ducts are also located above the ceiling in the central corridor. The return air ducts are on top of the inlet air ducts. Most of this return air is recirculated through the HVAC system. Approximately 4,000 CFM are diverted through the don/doff area and vented to the outside.

All weapons bays and support areas have ceiling heights that are below the plenum space in the corridor. Ceiling drops are used to provide air paths from the plenum down through the roof slab to the weapons bays and support areas. The airflow for this concept is illustrated in Figure 5-12.

5.3.5 Facility Concept No. 5

Concept No. 5 is a one-story design where the entire facility, including loading docks, is below grade. The volume of the region requiring chemical protection is 6.0×10^5 ft^3. The two loading docks are reached from the surface via sloping driveways. One of the loading docks is connected to a vestibule used for weapons loadout when the facility is under threat of chemical attack. This loading dock is also connected (via the vestibule) to the filter room and don/doff area. A forklift access route is provided between the loading dock and filter room to facilitate CBR filter changeout. In a chemical warfare scenario, both loading docks, the access ramps, the vestibule, the filter room, and parts of the don/doff area will be contaminated. The remainder of the structure is clean and under positive pressure.

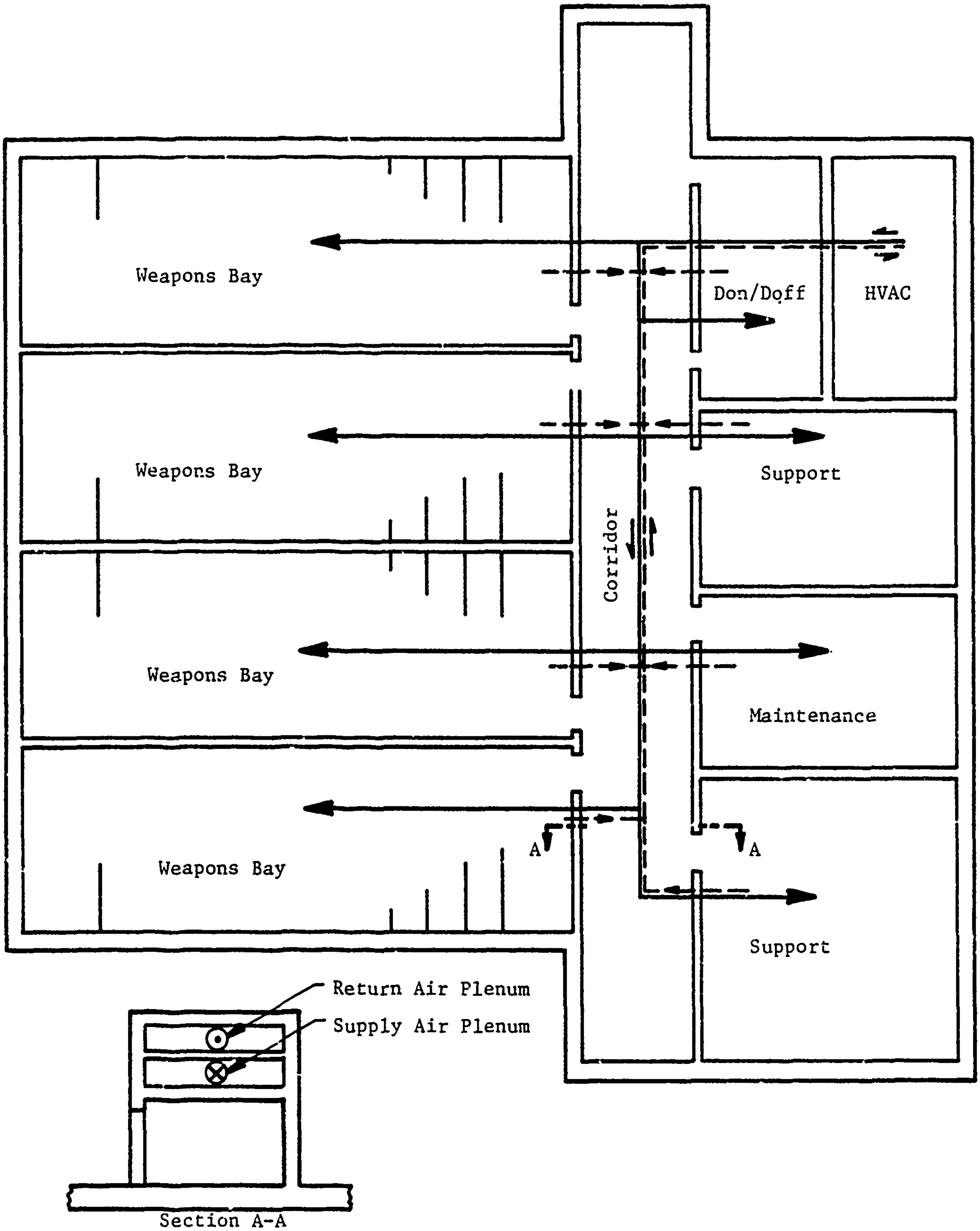


Figure 5-12. Airflow Network for Concept No. 4

This concept is very good from a chemical protection viewpoint because the only way for liquid chemical agents to reach the exposed parts of the facility is down the access roads leading to the underground loading docks. Very little direct deposit of agents will occur in this fashion. Most of the liquid contamination that does occur at the loading dock will be the result of working with contaminated trucks. Chemical agents in vapor form will be the major threat to this facility.

Outside air is ducted directly to the underground CBR filters for removal of toxic liquids and vapors. The airstream is then passed through the HVAC equipment housed in a room adjacent to the filter room. The filtered and conditioned airstream is distributed to the remainder of the facility through ducts located above the ceiling in the square-shaped central corridor. Pressure monitors control dampers in the ducts to maintain a positive pressure of at least 0.3 in. H_2O in the uncontaminated parts of the facility.

Return air from the rooms and bays is directed to a plenum on the outer bay walls opposite the corridor. The airflow for concept No. 5 is very similar to that illustrated for Concept No. 1 in Figure 5-9. The return plenum channels most of the return air back to the HVAC system for recirculation. Approximately 4,000 CFM are diverted through the don/doff area and vented to the outside.

5.3.6 Facility Concept No. 6

Concept No. 6 is completely buried except for one of the two loading docks. The aboveground dock is reached via a platform lift. The underground dock is serviced by a sloping access road. The aboveground dock is the one used for weapons loadout in a chemical environment. This dock is also connected (via the lift) to the underground CBR filter room and don/doff area. A forklift access route is provided from the aboveground dock to the filter room for use in the filter changeout process. In a chemical warfare scenario, both loading docks, the platform lift, the driveway, the vestibule, the filter

room, and parts of the don/doff area will be contaminated. The remainder of the structure is clean and under positive pressure. The total volume of the protected region is 5.5×10^5 ft^3.

Outside air is first directed through the CBR filter network for removal of toxic liquids and vapors. The airstream is then passed to the HVAC system located in a room down the corridor from the filter room. The filtered and conditioned airstream is distributed throughout the building via a supply air plenum located above the ceiling along most of the center corridor. As with Concept No. 4, the weapons bays and support areas have ceiling heights below that of the supply plenum. Consequently, ceiling drops are again used in these areas to bring supply air into the bays. Pressure monitors and dampers are used to control airflow in the plenum so that a positive pressure of at least 0.3 in. H_2O is maintained in the uncontaminated areas of the facility.

Return air from the various rooms and bays is routed through an air space in two of the exterior walls and through a plenum extending over part of the corridor near the underground loading dock. The airflow is illustrated in Figure 5-13 for Concept No. 6. Most of this return air is recirculated through the HVAC system. Approximately 4,000 CFM of the return air are bled off and diverted through the don/doff facility. Excess flow through the don/doff facility is vented to the outside.

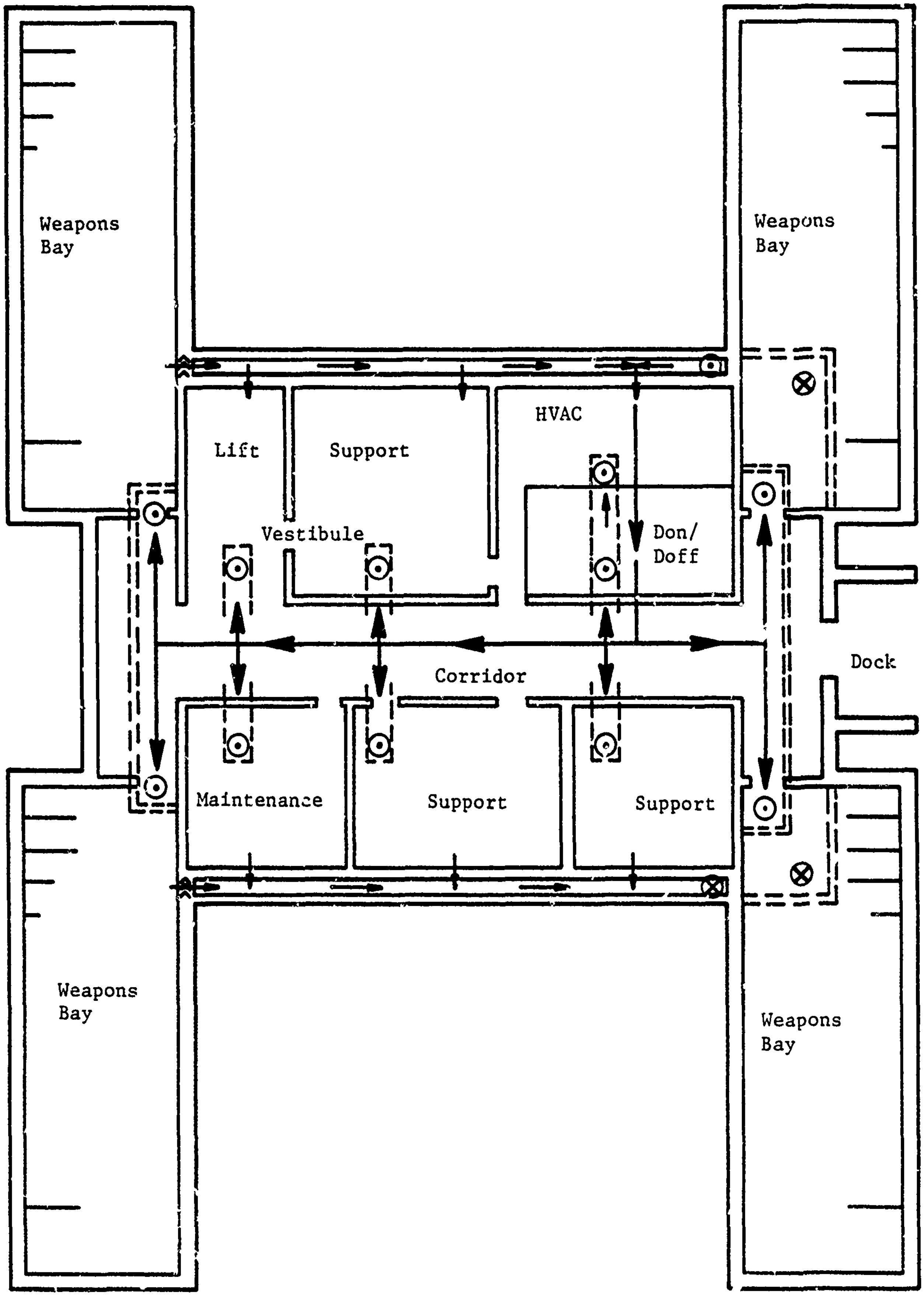


Figure 5-13. Airflow System for Concept No. 6

5.4 Weapon Loadout

The following paragraphs discuss workflow and weapon loadout considerations for six specific weapon storage facility layouts. Concept drawings of each layout can be found in Section 5.5.

5.4.1 Facility Concept No. 1

Concept No. 1 is a completely aboveground structure. The two loading docks are located on opposite sides of the building with a corridor connecting them through the center of the building. Road or rail access can be provided at each dock. The four weapon bays all open off of one side of the center corridor. Each bay has easy access to either loading dock. Within each bay, the 16 weapon cubicles are stacked two high along one wall.

All weapon movement and handling is accomplished with forklifts. No overhead cranes are required in the weapon bays. For loadout, the forklift picks up each weapon from the end of the container, backs it out of the storage cubicle and drives forward to the corridor. The forklift then moves with the weapon to the nearest loading dock and drives directly onto the truck bed before setting it down.

All four bays can be unloaded simultaneously. Each dock can accommodate two trucks in loading positions at the same time. Complete loadout of the 57 weapons in the facility can be accomplished in approximately 1.2 hours (not including weapon tiedown on the trucks). The following personnel and equipment are required to support this activity:

- 11 personnel
- 4 forklifts
- 23 trucks (including drivers).

Loadout in a chemical environment is accomplished using only one loading dock. Forklifts bring the weapons to the corridor near the vestibule. The weapon is placed on a rotating roller pad, turned 180 degrees, and pushed down a track through the weapons door into the vestibule. A forklift, driven by an individual in chemical defense gear, picks the weapon up in the vestibule and places it on the truck.

5.4.2 Facility Concept No. 2

Concept No. 2 is a completely aboveground structure. The two loading docks are located on opposite sides of the building with a corridor connecting them through the center of the building. Road or rail access can be provided at each dock. Two weapon storage bays are located on each side of this corridor. Each bay has easy access to either loading dock. Within each bay the weapon cubicles consist of pits located below floor level, 16 pits per bay. The pits are arranged along two sides of the bay with an aisle in the middle.

An overhead crane is used to take the weapons in and out of the storage pits. For loadout, the crane lifts the weapon out of the pit and places it on the center aisle of the bay, oriented so that the proper end of the canister is accessible to a forklift. The forklift picks up the weapon, backs down the aisle to the corridor, and then drives forward to the loading dock where the weapon is deposited on a waiting truck. While the forklift is traveling, the crane is setting the next weapon into the aisle. The timeline analysis for this particular layout indicates that the crane operations are faster than the forklift operations, so a weapon is waiting each time the forklift returns to the bay.

All four bays can be unloaded simultaneously. Each dock can accommodate two trucks in loading positions at the same time. Complete loadout of the 57 weapons in this facility can be accomplished in approximately 1.3 hours

(not including weapon tiedown on the trucks). The following personnel and equipment are required to support this activity:

- 11 personnel
- 4 forklifts
- 4 overhead cranes
- 23 trucks (including drivers).

Loadout in a chemical environment is accomplished using only one loading dock. Forklifts bring the weapons to the corridor near the vestibule. The weapon is placed on a rotating roller pad, turned 180 degrees, and pushed down a track through the weapons door into the vestibule. A forklift, driven by an individual wearing chemical defense gear, picks the weapon up in the vestibule and places it on the truck.

5.4.3 Facility Concept No. 3

Concept No. 3 is a two-story design, with one level below grade and one level above grade. The two loading docks are on the top level on opposite sides of the building, and can provide for either road or rail access. The four weapon storage bays are below ground. They are arranged with two bays on each side of a center corridor. The corridor has a platform lift at each end. On the top level, the lifts open onto the loading docks. Each underground storage bay has easy access to either of the platform lifts. Within each bay, the 16 weapon cubicles are stacked two high along one wall.

All weapon movement and handling in this concept is accomplished with forklifts. No overhead cranes are required in the weapon bays. For loadout, the forklift picks up each weapon from the end of the container, backs it out of the storage cubicle, and drives forward to the corridor. The forklift then moves the weapon down the corridor to the nearest lift, rises to the surface level, and drives the weapon onto a truck waiting at the loading dock.

All four bays can be unloaded simultaneously. Each dock can accommodate two trucks in loading positions at the same time. Complete loadout of

the 57 weapons in the facility can be accomplished in approximately 1.8 hours (not including weapon tiedown on the trucks). The following personnel and equipment are required to support this activity:

- 11 personnel
- 4 forklifts
- 23 trucks (including drivers).

Loadout in a chemical environment is accomplished using only one loading dock. Forklifts bring the weapons to the corridor by the vestibule on the lower floor. The weapon is placed on a rotating roller pad, turned 180 degrees, and pushed down a track through the weapons door into the vestibule. A forklift, driven by an individual in chemical defense gear, picks the weapon up, enters the lift, rises to the top floor, drives the weapon onto the truck bed, and sets it in place.

5.4.4 Facility Concept No. 4

Concept No. 4 is a one-story design that is completely buried except for two loading docks. The docks can be linked to either road or rail systems. The four weapon storage bays are all on one side of a central corridor. A platform lift to the surface loading docks is located at each end of this corridor. Each underground storage bay has easy access to either lift. Within each bay, the 15 weapon cubicles are lined up along one wall.

All weapon movement and handling in this concept is accomplished with forklifts. No overhead cranes are required in the weapon bays. For loadout, the forklift picks up each weapon from the end of the container, backs it out of the storage cubicle, and then drives forward to the corridor. The forklift then moves the weapon down the corridor to the nearest lift, rises to the surface level, and drives the weapon onto the truck waiting at the loading dock.

All four weapon bays can be unloaded simultaneously. Each dock can accommodate two trucks in loading positions at the same time. Complete loadout

of the 57 weapons in the facility can be accomplished in approximately 1.9 hours (not including weapon tiedown on the trucks). The following personnel and equipment are required to support this activity.

- 11 personnel
- 4 forklifts
- 23 trucks (including drivers).

Loadout in a chemical environment is accomplished using only one loading dock. Forklifts bring the weapons to the corridor by the vestibule. The weapon is placed on a rotating roller pad, rotated 180 degrees, and pushed down a track through the weapons door into the vestibule. A forklift, driven by an individual in chemical defense gear, picks the weapon up, enters the lift, rises to the surface, drives the weapon onto the truck bed, and sets it in place.

5.4.5 Facility Concept No. 5

Concept No. 5 is a one-story design where the entire facility, including loading docks, is underground. The two loading docks are reached from the surface via sloping driveways. One of the driveways could be replaced by rail access if so desired, provided that sufficient real estate is available to accommodate the gentle slopes required. The building is centered on the maintenance area, with a square corridor surrounding it. The loading docks are located opposite each other on two sides of the corridor. Weapon storage bays are located on the remaining two sides of the corridor, two bays per side. Each bay has easy access to either loading dock. Within each bay are 16 weapon cubicles. Each cubicle is surrounded by dividing walls on all four sides. Eight cubicles are arranged along each of two bay walls, with a center aisle in between.

Since there is no forklift access through the dividing walls, a crane must be used to lift the weapons over the top of the dividing walls. For loadout the crane lifts the weapon out of the cubicle and places it on the center aisle of the bay, oriented so that the proper end of the canister is accessible to a forklift. The forklift picks up the weapon and backs down the aisle to the central corridor. The forklift then drives forward to the loading dock where the weapon is deposited on a waiting truck. While the forklift is

traveling, the crane is setting the next weapon into the aisle. The timeline analysis for this particular layout indicates that the crane operations are faster than the forklift operations, so a weapon is waiting each time the forklift returns to the bay.

All four bays can be unloaded simultaneously. Each dock can accommodate two trucks in loading positions at the same time. Complete loadout of the 57 weapons in this facility can be acccomplished in approximately 1.3 hours (not including weapon tiedown on the truck). The following personnel and equipment are required to support this activity:

- 11 personnel
- 4 forklifts
- 4 overhead cranes
- 23 trucks (including drivers).

Loadout in a chemical environment is accomplished using only one loading dock. Forklifts bring the weapons to the corridor near the vestibule. The weapon is placed on a rotating roller pad, turned 180 degrees, and pushed down a track through the weapons door into the vestibule. A forklift, operated by an individual wearing chemical defense gear, picks up the weapon in the vestibule and places it on the truck.

5.4.6 Facility Concept No. 6

Concept No. 6 is a completely underground facility, with the exception of one surface loading dock. A platform lift connects the underground bays to the surface dock. The second loading dock is underground. Trucks reach this dock by backing down a sloped ramp. The underground structure resembles an "H," with maintenance and support bays located on the center crosspiece, and the four weapon bays extending outward from this center section. A long corridor runs down the middle of the center section and branches into four short corridors leading to the weapon bays. These corridors give each bay relatively easy access to both the aboveground and underground loading docks. Within each bay, the 15 weapon cubicles are lined up along one wall.

All weapon movement and handling in this concept is accomplished with forklifts. No overhead cranes are required in the weapon bays. For loadout, the forklift picks up each weapon from the end of the container, backs it out of the storage cubicle, and then drives forward to the corridor. The forklift then moves the weapon down the corridor to the underground dock, or to the platform lift leading to the surface-level dock. The forklift drives onto the truck bed before setting the weapon down.

All four weapon bays can be unloaded simultaneously. Two bays use the surface dock, and two use the underground dock. Loadout to the surface dock is the most time consuming. Complete loadout of the 57 weapons in the facility can be accomplished in approximately 1.9 hours (not including weapon tiedown on the trucks). The following personnel and equipment are required to support this activity:

- 11 personnel
- 4 forklifts
- 23 trucks (including drivers).

Each loading dock can accommodate two trucks in loading positions at the same time.

Loadout in a chemical environment is accomplished using only the surface loading dock. Forklifts bring the weapons to the corridor by the vestibule. The vestibule is located underground next to the entry to the platform lift. The weapon is placed on a rotating roller pad in the corridor. It is rotated 180 degrees and pushed down a roller track through the weapons door into the vestibule. A forklift, driven by an individual wearing chemical defense equipment, picks the weapon up, enters the lift, rises to the surface, drives onto the truck bed, and sets the weapon in place.

5.5 Structure Resistance Time

In estimating the time a structure will resist commando squad attack, it was necessary to make several assumptions. First, the size of the attack force was limited to 15 or fewer persons. Second, the equipment and weapons employed against the structure were limited to those items which could be brought in without vehicles. Third, it was assumed that the terrorists had obtained structural details. Finally, assumptions were made regarding the times involved in breaching a series of concrete walls and cutting rebars. These latter assumptions were discussed in Section 4.1.5.

Each of these assumptions was based on qualitative arguments. Limiting the attack force to 15 people is based on the logistics of supporting a clandestine organization. Groups much larger than 12 - 15 people are expected to be unable to support themselves and function in secrecy.

Vehicles have been disallowed in terrorist attack scenarios for several reasons:

(1) Vehicles can be more easily detected by warning and detection systems than can individuals on foot.
(2) The scenario of detonation of several thousand pounds of high explosive in intimate contact with the structure, which is possible when allowing large vehicles to approach the structure, seems unduly severe for a terrorist attack scenario.
(3) Times to penetrate the structure may not be improved by assuming that vehicles can be driven close by.

The terrorists are, therefore, assumed to have to cover the last 100 yards to the attack point on foot.

Knowledge of the shelter's construction details permit the terrorists to plan their attack more accurately. This information should be available from a variety of sources (i.e., satellite photographs, information from construction workers, and/or architectural plans).

For the aboveground storage concepts (Concepts 1, 2,and 3), three attack scenarios were considered. One scenario attacks a roof consisting of two feet of reinforced concrete followed by two feet of earth and four feet of reinforced concrete. In the second scenario, an air gap replaced the earth fill (wall situation). In addition, a 3/8-inch steel plate was assumed to back up the four-foot concrete slab. This plate served the dual purpose of functioning as a form during pouring and as a spall plate in the event of an attack. The third scenario considered an attack against a double door. This system includes two concrete sliding doors separated by a four-foot space (wall thickness). The doors are 18-inch-thick reinforced concrete. In each case the resistance time started when the terrorists were 100 yards away. As shown in Table 5-3, it should be possible for terrorists to gain entry in scenarios 1, 2, and 3 in less than 30 minutes. This time can be extended for scenario 1 by changing the construction. A steel plate ($\simeq$ 3/8 inch) behind the four-foot concrete slab will force the attacking squad to expend much more effort clearing debris and utilizing a burning bar. This modification should extend the entry time to beyond 30 minutes. Time for scenario 3 can also be extended by placing steel plates on the door faces. A 1/4-inch steel plate on the inside face of each of the doors should extend the entry time by approximately five minutes. This would bring the total time to enter to about 30 minutes.

An additional item to consider in Concepts 3 and 4 is the lift used to bring weapons up to the loading dock. The lift is the only penetration between floors designed to handle people or equipment. By designing the lift to be locked into place when it is not in use, the time required to gain access to the weapons can be extended. The terrorists would be required to cut through the platform or defeat the locking mechanism. Assuming the terrorists have reached the lift by breaching a double door as described in the third scenario presented in Table 5-3, the time to reach the weapons will be increased to approxmiately 30 minutes as a result of having to breach the lift. Considering the first scenario, the time would be increased to approximately 24 minutes if a lift must be breached.

Table 5-3. Summary of Resistance Times for Three Terrorist Attack Scenarios

Action	Scenario 1 (Seconds)	Scenario 2 (Seconds)	Scenario 3 (Seconds)
Cover last 100 yd to structure	60	60	60
Set explosive charge	300	180	180
Retreat and take cover	60	60	60
Return & set up equipment to cut rebar	120	120	120
Clear debris and cut rebar	600	420	240
Set second charge	N/A	300	300
Take cover	N/A	60	60
Return, clear debris, cut rebar and spall plates (Scenario #2)	N/A	540	480
Total time to obtain entry	1140 (19 Min)	1740 (29 Min)	1500 (25 Min)
Total quantity of explosive	1000 lb	200 lb	100 lb
Total quantity of burning bars	4 @ 10' ea	6 @ 10' ea	6 @ 10' ea
Total quantity of oxygen	3 - 80 ft^3 cylinders	4 - 80 ft^3 cylinders	3 - 80 ft^3 cylinders
Total number of persons required (minimum) (Based on ~100 lb carried per person)	13	6	5

Scenario 1 - Terrorist attack on 2' slab, 2' earth, 4' slab

Scenario 2 - Terrorist attack on 2' slab, 2' air, 4' slab, spall plate

Scenario 3 - Terrorist attack on 18" door, 4' air, 18" door

Concept 5 is entirely below ground. Because of its configuration, scenario 3, Table 5-3, should represent the attack scenario. For this design, the time can be extended by placing a heavy gate across the drives running down to the loading docks. As mentioned previously, the time can also be extended by adding steel plates to the concrete doors.

Concept 6 has one side configured similarly to concept 4. Therefore there are no new considerations to be made with concept 6.

5.6 Conceptual Drawings and Cost Estimation

Once the multitude of layouts had been reduced to six by the processes described in earlier sections, and once preliminary structural analyses had fixed types and materials of construction, and thicknesses for various structural components to meet the safety and security requirements and the external threats, then all sketches and layouts were turned over to our AE subcontractor for preparation of concept drawings and estimation of construction costs. They suggested a number of revisions and alterations to render the concepts more constructible and better operationally, and/or to minimize costs. Following review of their suggestions, final concept drawings were prepared, and construction cost estimates were completed. Figures 5-14 through 5-19 are reduced-scale copies of the layouts for each of the six concepts. Full-scale layouts and details of construction cost estimates appear in Appendix 3.

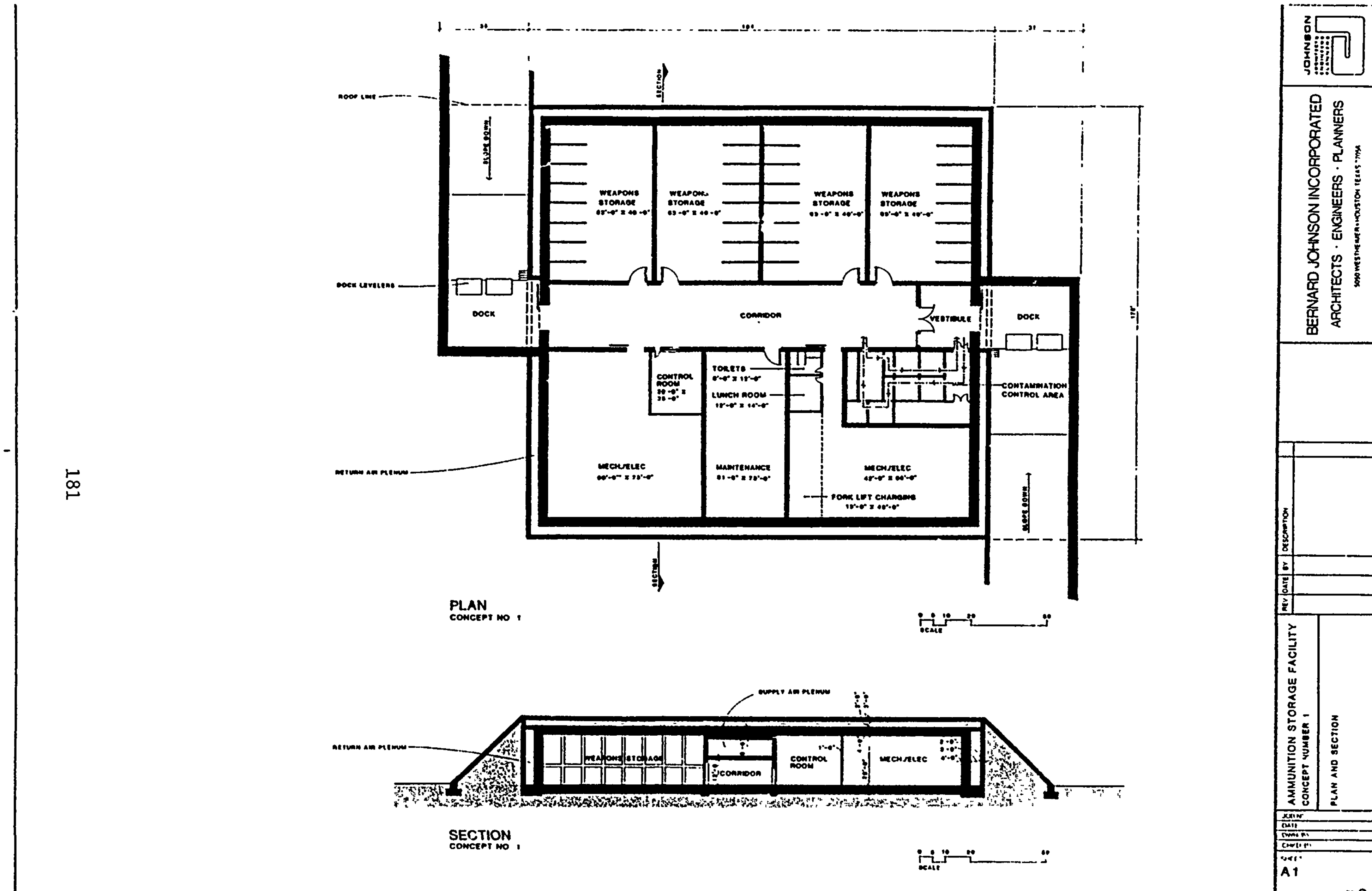


Figure 5-14. Reduced-Scale Copy of the Layout for Concept No. 1.

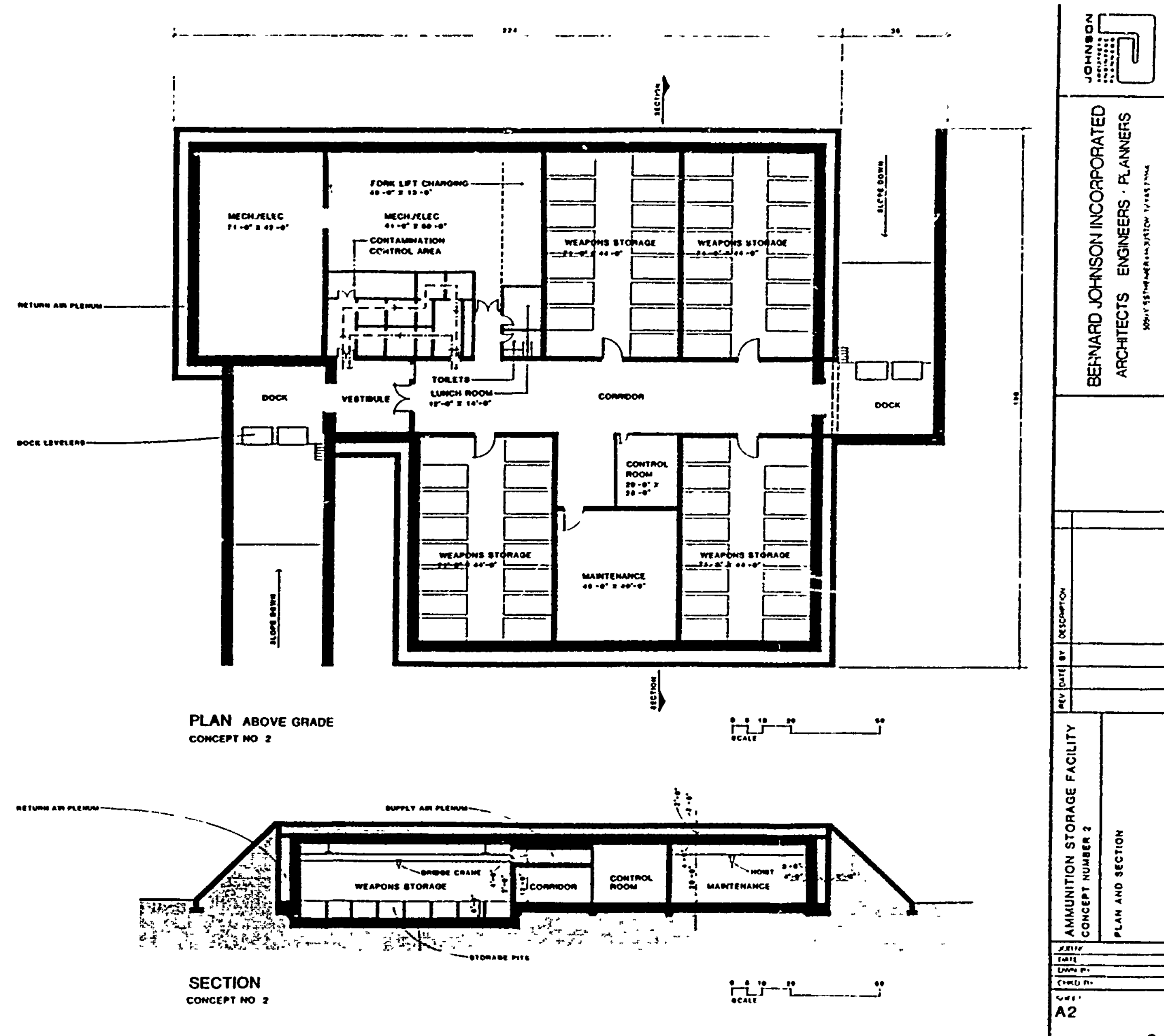


Figure 5-15. Reduced-Scale Copy of the Layout for Concept No. 2.

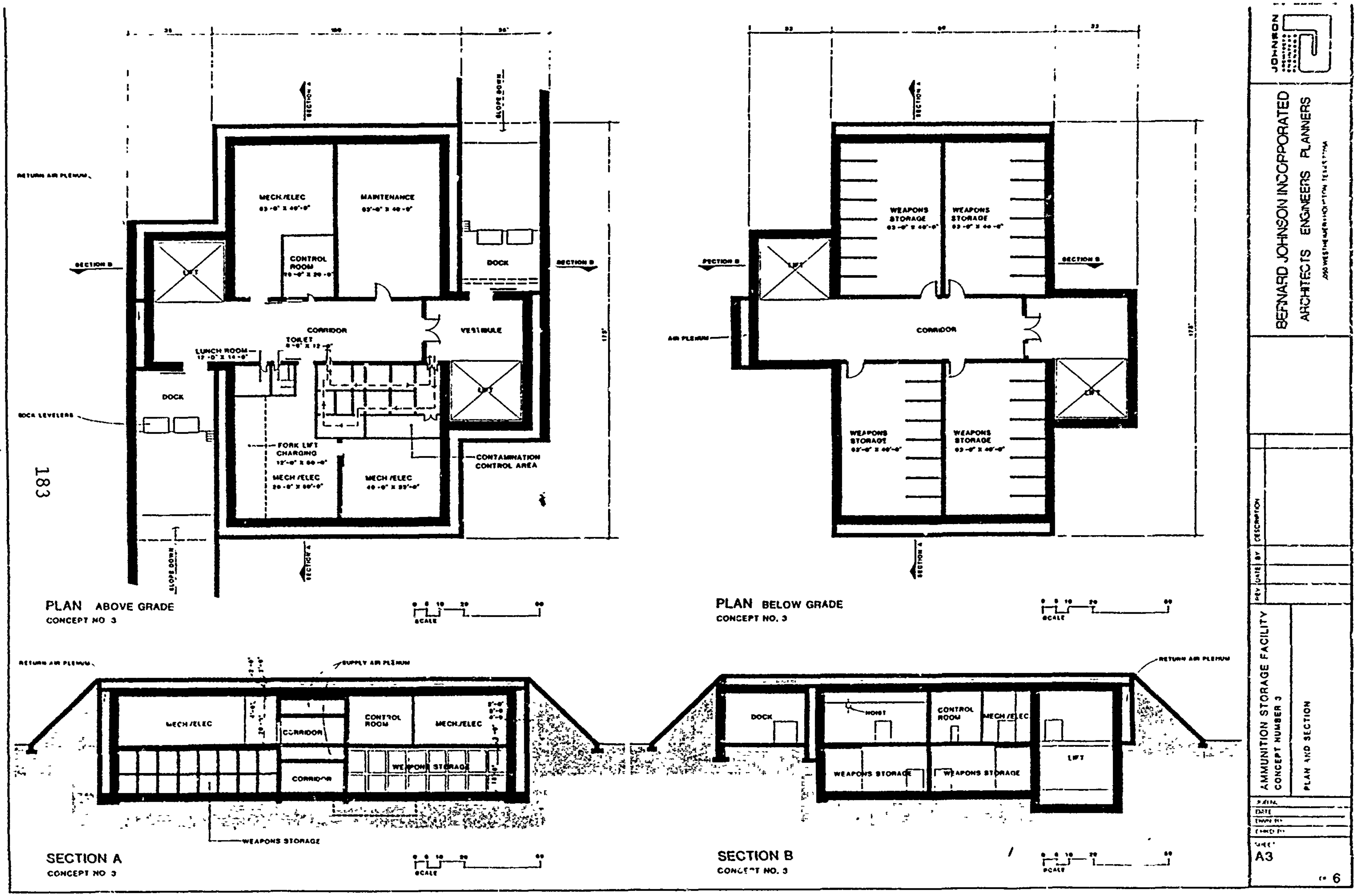


Figure 5-16. Reduced-Scale Copy of the Layout for Concept No. 3.

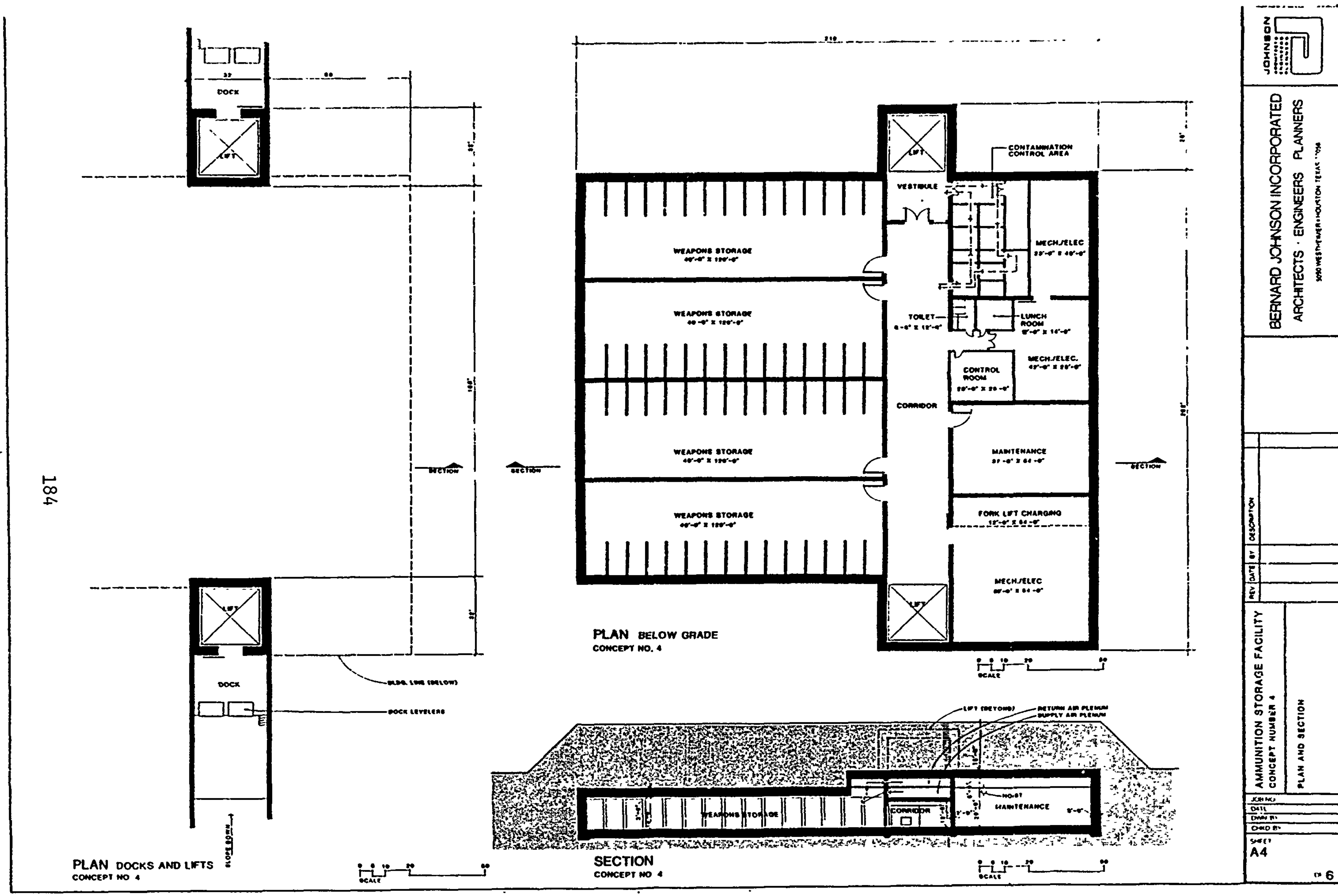


Figure 5-17. Reduced-Scale Copy for the Layout for Concept No. 4.

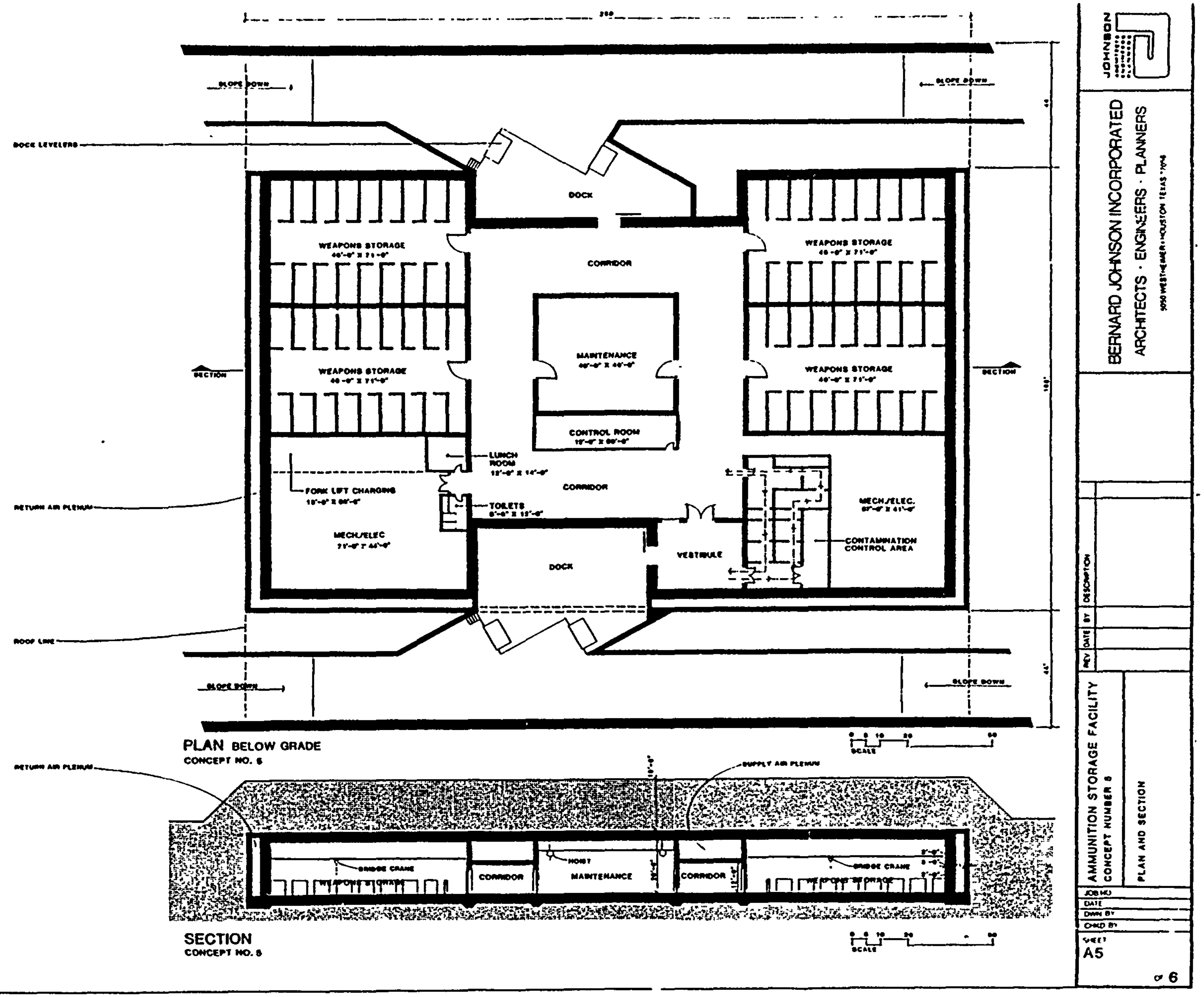


Figure 5-18. Reduced-Scale Copy of the Layout for Concept No. 5.

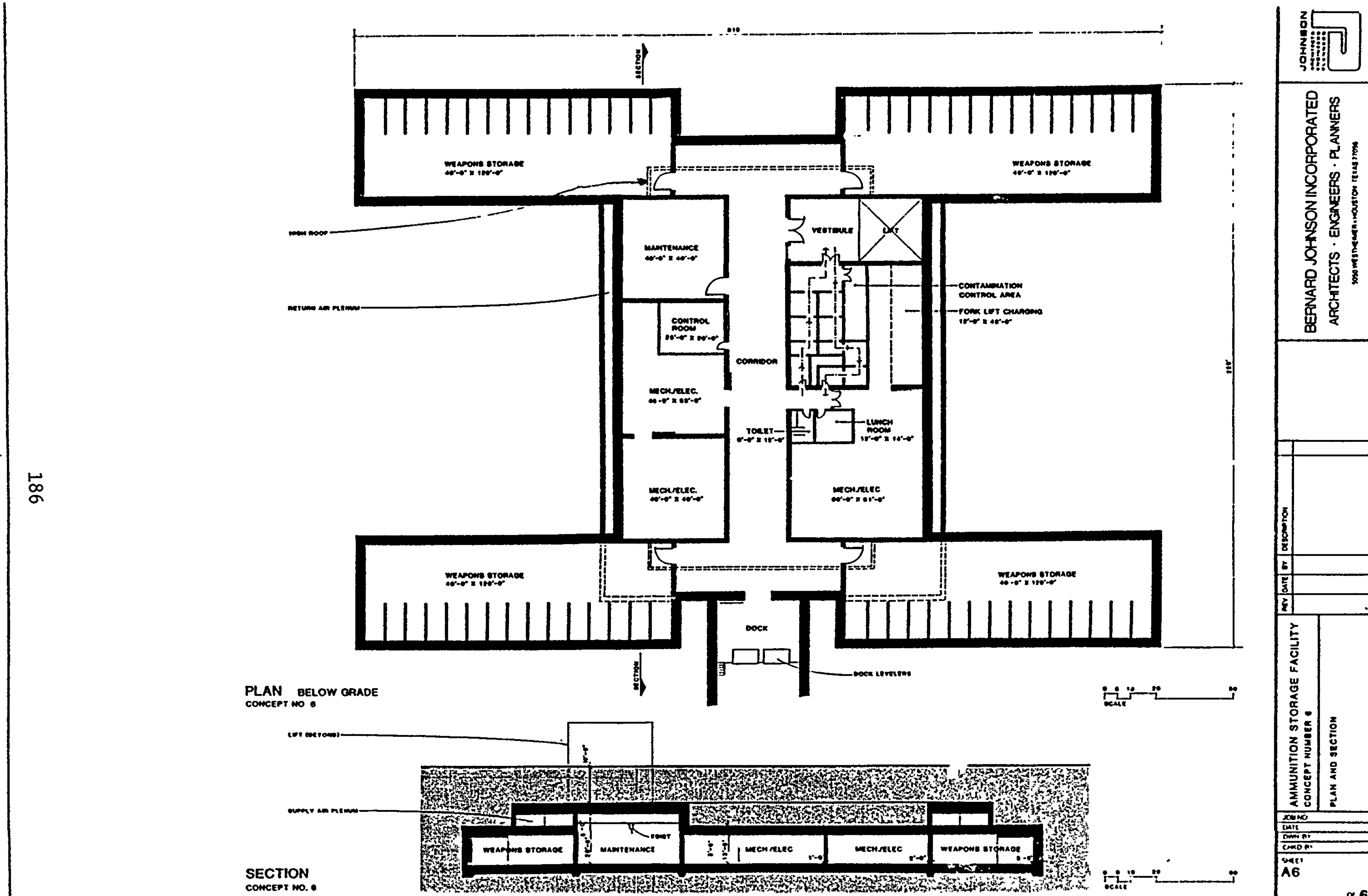


Figure 5-19. Reduced-Scale Copy of the Layout for Concept No. 6.

6.0 SELECTION OF THE FINAL THREE CONCEPTS

Because of our processes of eliminating concepts which could not survive the external security threats and attack environments, and designing the remaining ones to be essentially equally resistant to these threats, all six of the concepts presented in the previous Section rate equally on these factors. The criteria remaining for comparison of the concepts and further elimination are then:

- Cost
- Loadout time
- Operational efficiency in day-to-day operation
- Equipment needs.

Table 6-1 is a matrix summarizing the results of evaluating these four criteria for the six concepts. Examination of the costs associated with the concepts shows two clear break points. Concept 1 was least expensive and was thus assigned a "low" rating. Concepts 2, 3, and 5 clustered together with intermediate costs, and were given a "medium" rating. Concepts 4 and 6 were most expensive and were given a "high" rating. Examination of the six loadout times shows that they fall into two groups, with concepts 1, 2, and 5 being best (lowest) and concepts 3, 4, and 6 being highest.

The operational efficiency ranking in Table 6-1 reflects a judgemental evaluation on the part of the program team. Compact designs with easy access to maintenance and good centralized control were considered the most efficient for day-to-day operations. Efficiency of loadout was not part of this criterion. The ratings on equipment needs reflect the fact that forklifts are self-sufficient in terms of energy and are easily removable and replaceable in case of mechanical failure. Overhead bridge cranes have neither of these properties. Most of the bay layouts preclude replacing a failed bridge crane with a portable gantry crane. The evaluators felt that the use of lifts did not warrant increased or decreased rating points.

Based on the comparison shown in Table 6-1, it is recommended that the final three concepts be:

Concept No. 1

Concept No. 3

Concept No. 4.

Table 6-1.

Matrix of Deciding Criteria for Final Three Concepts

Criterion	Concept No. 1	2	3	4	5	6
Cost	1	2	2	3	2	3
Loadout Time	1	1	2	2	1	2
Operational Efficiency (subjective judgement)	1	3	2	1	3	2
Equipment Needs	1	2	1	1	2	1
	4	8	7	7	8	8

Cost		Loadout Time Hours	Points	Operational Efficiency Ranking	Points	Equipment Needs Type Equip.	Points
Low	1	Low	1	Most Efficient	1	Forklift	1
Med	2	High	2	Efficient	2	Forklift and Crane	2
High	3			Least Efficient	3		

7.0 CONCLUSIONS AND RECOMMENDATIONS

A number of layouts for munitions storage facilities were developed and compared. From these, six candidate layouts were then chosen and developed into more complete concept designs, with analyses of effects of a number of severe external threats and choice of configurations, materials, etc., to withstand each threat. These six concepts all meet the following criteria:

(1) No penetration into inner structure for an oblique crash of a Boeing 747 aircraft.

(2) No penetration of inner structure for direct hit by a 500-lb general purpose bomb.

(3) No collapse of inner structure for surface burst of 300,000 lb of high explosive at a standoff of 100 m from the nearest wall.

(4) Will be operational under chemical weapons attack.

(5) Will withstand a sophisticated terrorist attack for at least 30 minutes.

All six of these concepts are also constructible in level terrain with high water table and poor soil-bearing capacity.

Three design concepts (Concepts 1, 3, and 4) were then chosen for further study based on comparative costs, operational efficiency, minimum loadout times, and minimum amount of equipment. This study used the usual engineering approach of making the best conservative analyses, computations, and estimating methods available. However, these design concepts may be overconservative in order to resist several of the postulated threats. In particular, the loads imparted by a crashing large aircraft may be overestimated and the methods of predicting structural response and damage under this loading may be too conservative. This situation could be improved in further studies

by verifying crash loads (perhaps through model-scale testing), or more sophisticated dynamic structural response analyses, or both.

The choice of the final three concepts was based partly on numerical comparisons, but also to some extent on subjective judgment. The cost estimation procedures were not site-specific, but were based instead on assumptions of level terrain, and poor, saturated-soil conditions. Because final choices of concepts were based partly on construction cost estimates, it is quite conceivable that there will be differences in relative costs and, therefore, concept choices, given a specific construction site with known soil properties.

All of the concepts differ drastically in configuration, structural characteristics, size, etc., from most existing explosives or munitions storage and handling facilities. If one or more of these concepts is carried forward to final design and construction, a variety of supporting tests or analyses will be needed to verify the survivability and security aspects of the design to verify design adequacy and possibly to allow more efficient and less expensive construction.

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